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AFCRL 997

TACTICAL DECISION MAKING: I. ACTION SELECTION AS A FUNCTION OF TRACK LOAD, THREAT COMPLEXITY, RELIABLE DATA PRESENTATION AND WEAPON UNCERTAINTY

Wyatt R. Fox
W. H. Vance, Jr.

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November 1961

Operational Applications Laboratory
Deputy for Technology
Air Force Electronic Systems Division
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and

Detection Physics Laboratory
Air Force Cambridge Research Laboratories
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Bedford, Massachusetts

Project No. 4690, Task No. 46902

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FOREWORD

The study reported here is the first major experimental study in an applied research program on the subject of decision making in aerospace surveillance. This program itself was but one Task (46902) documented under Project 4690, Threat Evaluation and Action Selection. During the period when these experiments were conducted this project was the technical responsibility of the Detection Physics Laboratory of AFCRL under the direction of Mr. W. H. Vance, Jr., The laboratory studies in man-machine decision making, of which this is one, were conducted by the Operational Applications Laboratory of the Electronic Systems Division of AFSC. Many Air Force and contractor personnel contributed greatly to the conduct of these studies, chief amongst the groups being the Lockheed Electronics Company, (development and maintenance) Wolf Research and Development Corporation, and Northeastern University (research services in data collection and reduction) and, most importantly, the 3245th AC&W Squadron (Experimental) who provided the trained command and support personnel.

ABSTRACT

Performance measures from the first major experiment in a series on tactical decision-making for threat evaluation and action selection in aerospace surveillance are described. Two groups of experimental commanders performed under several levels of target track load and threat complexity conditions. The task of the commanders was: (1) to minimize damage to the weapon areas, (2) to destroy a maximum number of threatening vehicles, (3) to conserve counter weapons so as to consume a minimum of forces consistent with objectives (1) and (2) above and (4) to develop his own strategy under constraints imposed by the ground rules.

In order to provide some standard performance criteria, a sample of the experimental problems was solved analytically so as to represent both "good" and "poor" automated decision making and "idealized" or maximum human performance. Human empirical scores compared favorably with analytical performance measures. Human empirical performance continuously improved as a function of number of system runs.

REVIEWED AND APPROVED FOR PUBLICATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION*

This report is one of a series concerned with research in the evaluation of surveillance situations and the selection of appropriate actions. This particular portion of the work involves experimental investigations of executive control function in simulated environments generally representative of future tactical aerospace operational situations. These investigations are a part of the research activities in information processing conducted at L.G. Hanscom Field by the Detection Physics Laboratory, AFCRL, OAR and the Operational Applications Laboratory, ESD. Most of this research has been carried out under projects documented in Technical Area 760B, Surveillance Techniques, of ARDC's Applied Research Program. Although rather fundamental in nature (i.e., in the earlier or more basic phases of the applied research cycle) this work has been biased toward the types of activities involved in USAF surveillance operations.

The purpose of this particular section is to define the nature of information processing as an integral part of surveillance, to establish the general boundaries or limits of the areas considered, and to outline some of the underlying assumptions and general goals of this series of experimental investigations.

The effectiveness of the U. S. Air Force in any given mission depends partly on the type and quantity of operational tools available at that time; e.g., the weapons, aircraft, missiles, and supplies.

*This introduction, principally written by W. H. Vance, AFCRL Project Scientist for Project 4690, is essentially the justification for the work on tactical decision making and is the vehicle which dictated the direction of the OAL effort under Project 4690.

However, it also depends on when and how these tools are used, i.e., on command decisions. To a very large degree, the effectiveness of command decisions is dependent on the timely availability of pertinent information about the operational situation, and skillful evaluation of this situation in terms of the mission. The need to know the location of the enemy, his disposition and strength (as well as similar information about our own forces) is as old as war itself. Collecting and interpreting such data in an aerospace situation is the function of surveillance. Surveillance provides the basis for short term, immediate, or "tactical" decisions -- to scramble certain interceptors, or to launch missiles, or to divert bombers to a new target, or to release SAC for a full scale retaliatory raid -- i.e., when and how to utilize existing capability. Thus, surveillance represents an important element of many military command decisions; in fact in operational aerospace situations it becomes the critical element of the command decision process.

Surveillance is not a new function. It has been performed in the past; the Air Force has a certain surveillance capability today; it will need a vastly improved surveillance capability in the future. The operational surveillance capability today is determined by the equipment and personnel now available. Providing the best possible surveillance capability for the next few years is the mission of the development program, i.e., the System Program Offices. Providing fundamental knowledge, concepts, methods, and techniques on which to base development of equipment systems at some future time is the purpose of our research program.

As has been pointed out, surveillance has been performed in the past, and is performed today. Military commanders have always faced problems in optimum utilization of their forces -- they have always had difficulties in "acquiring information," in "evaluating the situation," and in "making command decisions." In recent years there has been great emphasis on the design and construction of equipment and systems to assist military commanders in these functions. Although great progress has been made in some areas, there is no doubt that our present capability for collecting, processing, and evaluating information, and effectively controlling military activities is entirely inadequate. Even more serious, any reasonable projection of future problems indicates that the situation is likely to get worse.

Why is this so? Why are we concerned with these same old problems? Since we managed to solve them well enough in past operations, what is so different about today's situations, and tomorrow's? Some study has been made of questions of this type, but a detailed discussion is beyond the scope of this report. For the present, a brief mention of a few of the more important factors affecting surveillance and command decision problems will suffice:

1. The availability of long range delivery systems means that aerospace operations can be conducted over much greater ranges than ever before. Consequently, operational situations must be observed, evaluated, and controlled over larger volumes of space, many of them on a global basis.

2. The high speeds of delivery systems have compressed the total time available for the entire information-evaluation-decision-action process to a matter of minutes. In many vital operational situations at least, we can no longer afford the luxury of staff conferences, or extensive reflection and consideration of the situation before a decision is made.

3. Many modern delivery systems are unmanned and unrecallable, so that once action is initiated (e.g., to launch) there is little or no opportunity for modification of the decision. Thus, while there is need for faster decisions, they also must be reliable.

4. The advent of thermonuclear weapons, with vastly greater destructive capability than ever existed before, has significantly affected the evaluation-decision process in several ways, for example, the terrible consequences of a "wrong" decision. The problems are also complicated by the unknowns caused by the lack of experience in the actual use of such weapons; consider that only two atomic bombs have ever been exploded in anger, both of them quite puny by today's standards!

5. The necessity to evaluate and control situations larger in scope (1 above) with a shorter reaction time (2 above) has pushed the critical decision and control level higher and higher in the organizational hierarchy. Similarly, the unfamiliar nature of nuclear war and the potential impact of "wrong" decisions (3 and 4 above) have strongly reinforced the traditional desire for centralized, high level decision-making and control. Although similar problems have existed before

at "tactical command" levels, their emergence at the highest "national" levels is new.

6. The same weapons which emphasize the urgency for reliable centralized control create a host of impediments to achieving it. Information must be collected over greater volumes and communicated over long distances, thus tending to reduce the quality, timeliness, and reliability of the data; the effects of delays and errors in decision-making are magnified; sensing devices, communication links, and commanders are more vulnerable, etc.

Thus, even from this brief discussion, it is apparent that rapid advances in military technology have created a whole host of new problems in the collection, evaluation, and processing of information for control of aerospace operations. In the most stringent cases, information must be collected on a global basis, assembled at a central point at the highest national levels, and decisions made and implemented, all in a few minutes at most! However, even in more restricted military operations (e.g., "limited war") the areas involved are likely to be more extensive, certainly the necessary reaction time will be less, and decisions must be made at higher organizational levels than in the past.

In the tense world situation, with several countries already in possession of nuclear armament and others nearly so, there has been a re-awakening of interest in "controlled disarmament" and "arms control." Again, a detailed analysis of the information-evaluation-decision requirements for effective and reliable "inspection"

and "arms control" is beyond the scope of this report. It is interesting to note, however, that they bear a striking resemblance in many respects to the similar needs for effective control of actual military operations.

Surveillance is an information processing and control function. In a basic sense it is similar to any "management" or "control" system. There are four essential elements in any control system:

1. Some established goal or objective.
2. Some means of obtaining information about the situation.
3. Evaluation of the situation against some criteria (derived from the goal or objective), and determination of what action should be taken, within available resources, to modify the situation to achieve the objective.
4. Implementation of the necessary action.

Considerable work has been done on outlining the general characteristics of probable future operations from the specific viewpoint of surveillance, in defining the general parameters of the surveillance function in these classes of operational situations, and in isolating the critical areas and limits or constraints imposed by the nature of the operational problems. This work is reported elsewhere (19 ,20) and will not be discussed here in detail. The following brief comments on the four essential elements of the surveillance function derive largely from these studies.

Objectives or Goals. It is fundamental (though often not clearly understood) that military operations, or the ability to conduct them, exist as an element of our foreign policy. The only reason for defense and military preparations, and for actual military operations as well, is to strengthen thenegotiating arm of our diplomatic representatives starting with the President. Thus, the objective or goal in any surveillance system must derive from our national policy.

Of course, this does not mean the personnel engaged in research and development must be involved in the formulation or even the detailed study of national policy. However, they must understand that this relationship exists and consider the effects of major elements of our national policy on the function of surveillance. For example, as discussed earlier, it is only recently that the nature and tempo of military operations have changed so as to demand more and more detailed control to be exerted at the higher command levels. The increased range and speed of delivery systems coupled with the vast destructive potential of the weapons themselves has dictated a closer interaction between military control systems (such as surveillance) and national objectives and strategies.

In part because of this close interaction with national objectives and strategies, more and more attention has been given to "peacetime" or pre-hostilities information processing problems. This has led to the concept of deterrence through the threat of immediate massive retaliation. Thus, we have the problems of maintenance and control of a large peacetime force in being, with a large

part of this force in a high state of readiness, and detailed pre-planning for various contingencies to permit faster response and decreased vulnerability. Effective deterrence requires a demonstrated capability to prevail if war occurs. It is not enough to have the weapons and delivery systems, we must also have the capability to determine when and how to use them as an effective element of our foreign policy, to adjust their state of readiness, to shift their locations or concentration, to modify their capability, etc., as well as their employment in an operational sense if the occasion demands. To serve properly our national objectives and strategies, we need a surveillance capability effective in peace, in cold war, and in actual hostilities of all types, in limited war as well as in general war. We have needs for information collection and processing on a scale previously unheard of, and we need a capability for evaluation and decision-making of the greatest flexibility and the highest levels of sophistication.

Collect Information. Surveillance deals with aerospace situations. Hence, we must obtain information about all types of aerospace targets: aircraft, ballistic missiles, satellites, etc. We need to obtain such information over much larger volumes of space than ever before, and we need to obtain it quickly. We need to detect such targets, to determine the type or classification of each, to determine what they are doing, what they are capable of doing, and what they intend to do!

Much of this information cannot be measured or sensed

directly, but must be calculated or inferred. The most that our sensors can do is to measure signals, or observe effects which are indicative of physical parameters. Even these observations will be more or less incomplete and inaccurate, i.e., will contain varying amounts of noise. The problem is further complicated by the fact that (at least in many situations) we will be unable to locate our sensors in places which would give us the best information. Also, due to the necessity to communicate over long distances, data will be subject to further degradation, both in timeliness and quality.

Evaluate Situation and Determine Action. Since the data from our sensors are incomplete and inaccurate, we cannot know what the true situation is. At best we will have some indications or cues as to certain parameters of the situation. We must operate on these "noisy" data, and fill in the blanks or unknowns to create the best representation of the actual situation. We must then evaluate this admittedly inaccurate picture of the situation and determine the best utilization of our available resources.

This is an information processing problem, and a major portion of the Air Force research program in information processing is directed toward improving our capability in areas pertinent to this type of problem. It is significant that many of the functions which must be performed are closely analogous to human processes, so that investigation of human performance may provide valuable inputs in our efforts to express these functions mathematically and to design devices to perform them automatically. In fact it appears probable

that the greatest payoff may come from more effective integration of the high speed, large storage capabilities of machines with the judgment of human operators. This is particularly true when considering the high level, executive control function. It seems clear that this process will not be delegated to a mechanical device, no matter how sophisticated.

Implement Necessary Action. In order for any control system to function, the capability must exist to implement the necessary action. Although this function is outside the realm of surveillance, it is necessary to know what action can be taken (i.e., the available resources) in order to select the most appropriate action. It is also necessary to observe the results of the action in order to reassess the situation. Surveillance is a dynamic process, which continually observes and evaluates the situation, and initiates new actions as appropriate.

As we have noted, present and future surveillance operations require information processing on an entirely new scale, both in quantity and in sophistication. While the overall situations are more complex, the necessary reaction time is markedly less, and the available data contain errors and omissions. In many cases, significant information is buried in noise, has been altered or distorted by the environment (or by processing), or is deluged by quantities of less important details. Large numbers of variables must be manipulated simultaneously, with varying weights depending on the parameters of the situation. Clearly, these are not deterministic

processes, but are statistical or probabilistic in nature. Yet most of our large scale computers are deterministic devices.

A portion of our current research program is investigating various approaches for constructing mathematical models and evolving concepts and techniques for mechanizing processes of this type, e.g., research in mathematical statistics, game theory, utility theory, queuing theory, and decision theory; research on system theory, synthesis, and simulation; research on adaptive processes, learning, pattern recognition, correlation techniques, etc.

Many of these functions involve processes normally associated with human intelligence, such as learning, reasoning, recognition (or perception), inference, etc. Although the vast quantities of data, and the fast reaction time emphasize the need for automation, the current state of knowledge does not permit mechanization of such processes, except perhaps in very simple situations. Since man does learn, recognize, reason, etc., experimental investigations of his performance in carefully controlled environments can provide a valuable tool in better understanding the basic mechanisms involved in these processes. Such data will complement the more abstract studies in the search for concepts and methods for more sophisticated automation.

At the higher organizational levels, the nature of the problems and the potential impact of the decisions dictate the continuing need for human participation, at least as a monitor and as a final arbiter. Man's role in these processes and the extent and nature of his

affiliation with a machine complex for optimum performance is relatively unexplored, particularly in complex, time-constrained, multiple alternative situations, under conditions of high stress, variable risks, and dynamic environments. This type of problem also is amenable to experimental investigation.

This particular report deals with the portion of our research program concerned with experimental investigations of man-machine performance in a variety of situations representative of the problems outlined above.

A simulation facility has been developed at AFCRL (9,28) with the capability of simulating a wide variety of situations of varying degrees of complexity. Utilizing this facility, a series of experiments has been conducted in which human operators were required to analyze and evaluate data representing dynamic operational aerospace situations, to make appropriate decisions, and to initiate corrective action. The objectives of this type of experimentation may be divided into two general classes:

1. Investigation of human performance in such processes as recognition (or perception), learning, reasoning, inference, etc., and derivation of mathematical models of these processes.
2. Determination of fundamental criteria and parameters of man-machine interrelationships in evaluation and decision-making in complex situations.

Initial experiments have concentrated on the latter type of problem. Although some consideration has been given to the executive control problem at the highest national levels (e.g., Presidential level decisions in the general war case) (19), it was decided to examine experimentally the threat evaluation and action selection function (i.e., the executive control function) in a generalized tactical aerospace environment. There were several reasons for this decision. For one thing, the Presidential level is involved in many other decision problems not directly related to the military operations. Also, it is much simpler (although still quite difficult) to simulate reasonable situations. Then too, it was felt that many of the aspects of the problems are reasonably similar such that considerable extrapolation of results can be made both to higher and lower organizational levels.

In essence, this is a problem of making optimum decisions in very complex situations, based on uncertain data, and under conditions where the possible choices of action have uncertain results. Many unforeseen situations must be handled, and frequently the "rules of the game" are known only in a general sense, so that an effective decision-making strategy cannot be prepared in advance. The information processing system must be able to derive dynamically the detailed rules of the game, to adjust automatically its performance to these changing rules, and to adapt its strategy to the actual situations presented. Thus, although general criteria for evaluating the situation normally stem from the "goals or objectives", the detailed criteria and strategy must be developed within the control complex as the operation progresses.

Through such experiments it is hoped to derive information on (or at least gain a better insight into) some of the more critical elements of evaluation and decision-making in complex situations, for example:

1. The basic parameters of the decision process and how they are related:

(a) Can complex decisions be reduced to definable parameters which can be varied individually for study?

(b) Methods for reducing complexity of decision making alternatives; e.g., sequential vs parallel decisions, "natural" matrices for certain classes of decisions, etc.

(c) Effects of type and quality of input data on decision processes; e.g., effects of "noise" or inaccuracies in input data; does missing information pose the same problems as uncertain data; effects of delays in receiving data (i.e., timeliness); effects of approximation or summarization of information (i.e., filtering), etc.

(d) Effects of different types of erroneous decisions on the decision processes; e.g., if "wrong" decision can be catastrophic, does this tend to inhibit or delay making any decision; is there a tendency to make "easy" decisions first even if they are relatively unimportant; how to handle important, but extremely low probability events, etc.

2. The critical aspects of man-machine interrelationships in the evaluation-decision process:

(a) Effective criteria for optimum trade-offs between

men and machines; what functions must man perform and what functions can be assigned to machines; are these fixed, or do they change in a dynamic situation, etc.

(b) Essential parameters for man to serve effectively as a monitor (i.e., a safety check) and as commander (i.e., final arbiter).

(c) Effects of overloading; e.g., does effectiveness of man-machine complex collapse suddenly at critical overload, or deteriorate slowly; can the complex recover effectively as overload decreases; how to prevent or minimize effects of overload, etc.

(d) Criteria for altering decision strategies and dynamic revision of processing procedures; how determined; how best communicated to machine elements, etc.

(e) Functional specifications for displays and controls, e.g., how best to present a situation summary; how to query machines; essential elements of common man-machine language.

3. Significant parameters of human performance in evaluation and decision-making:

(a) Procedures utilized by man in such processes as recognition (or perception), learning, reasoning, inference, etc. Can these procedures be expressed as mathematical models; can they be related toexisting theories, e.g., decision theory, etc.

(b) Methods for handling uncertainties, missing data, errors, delayed data, etc.

(c) Limitations imposed by human characteristics

on efforts to integrate closely man-machine activities.

(d) Identification of personality or other factors which could predict "good" or "poor" performance as a decision-maker.

(e) Methods for testing mathematical models or automatic devices, vs human performance in decision-making.

(f) Effects of overloads, stress, high risk, etc., on human decision-making.

This experimental program is aimed primarily at exploring the basic principles of the general problems of evaluation and decision-making in complex situations. While the generality of the problem has been maintained to the maximum extent possible, it has been necessary to select more specific situations for simulation, i.e., the threat evaluation and action selection function in a generalized tactical aerospace environment. Consequently, it is expected that certain information or principles of system design and operation, will derive automatically which may find application in more immediate system problems. While this is not a primary goal of the research, this type of information will be identified and reported as appropriate.

Many approaches have been employed to investigate tactical decision-making as related to field and operation type situations. Exercises are constantly being run by all service elements to evaluate specific force combinations related to their missions. Human decision-making as related to air surveillance systems (31, 32) has recently been surveyed in detail. Story (29) has recently published a report on the general problem of defining system performance

criteria. Glaser and Wilson (13) have proposed a mathematical model for use in tactical decision-making research.

However, in spite of all this effort, little experimental work has been accomplished to define parameters relevant to decision-making as it relates to surveillance techniques. Mackworth (17) appears to be one of the first to investigate this area with work in the context of decision-making problems in combat air operations of the British Fleet. Project Cadillac (7) experimentally investigated human threat evaluation and action selection performance in airborne CIC's. The Cornfield Program (25) appears to be the first investigation of threat evaluation and action selection in a general sense with a man-computer combination. In Cornfield, several experiments were run comparing human performance, computer performance, and man-computer interaction for processing a series of simulated naval air defense problems. Just prior to these studies, Chapman, et al (6) ran a series of experiments evaluating operational air defense crews, but the emphasis was on crew performance, rather than the decision processes involved. Currently, there are studies underway at Rand Corporation, System Development Corporation, and at Applied Physics Laboratory exercising the command function in terms of the decision-making involved, but in each case the results are specific to immediate systems.

Adequate experimental data on human command-decision behavior are still virtually non-existent. In attempts to fill this lack, the use of an aerospace surveillance simulator seems to have

advantages over the alternatives of logical analysis, single-variable laboratory experiments, and field exercises. The usefulness of these alternative approaches are recognized, but still they are less attractive for several reasons. Logical analysis is constrained by the validity of the underlying assumptions made about the human decision processes. Solid data are still lacking here. These may be supplied in part, by single-variable laboratory experiments, but this process is slow and is not suited to the detection and measurement of critical combinations of variables. There is also a lack of "realism" associated with these studies. Field studies produce data in terms of a realistic environment. They are difficult to control and assess, however, in that trials under the same conditions cannot be repeated, and the manipulation of a range of experimental variables is usually impossible.

The use of a simulation facility permits a reasonably realistic environment to be generated. This environment can be controlled to a degree not possible in the field. Thus, repeated trials under similar conditions and sufficient data points can be obtained to insure stable measures of the processes under consideration.

Feasibility of simulating tactical decision-making problems with the equipment used here was investigated by Doughty (9), Other studies were conducted to implement the capability of the facility (12, 28).

The experiment reported here is the first major experiment in a series designed to study man-machine performance in aerospace

command and control tasks of threat evaluation and action selection (TEAS). This experiment was concerned with the study of the effects of overall task load upon the performance of "tactical decision-makers" under circumstances in which the information supplied was essentially complete and correct. In addition, the threats which they were required to evaluate and counteract were of a conventional air-breathing sort. The major task of the "commanders" was the selection, from an inventory which varied in kind and number, of an appropriate choice of counter weapons, with the outcome of any action more or less uncertain. Actual evaluation of threat in relative or ab solute terms was only a small part of the job. The first major experiment was intended, in part, to establish some "base-lines" of human decision-making performance which, as noted in considering other studies, were not available from previous research.

SUMMARY

This experiment was the first major study in a series concerned with decision making in simulated, complex aerospace surveillance situations. Nine experienced commanders in two groups were required to evaluate the threat of and select counter-actions against a total of over 9,000 pre-programmed aircraft tracks in 120 experimental problem sessions plus a somewhat larger number of training sessions. Commanders were provided with a geographic situation display and auxiliary displays of identifying data as well as weapon status information. The objectives of this experiment were to establish some base-lines of human capabilities and limitations in complex, dynamic, real-time and realistic military decision making and to begin to describe the processes as well as to establish some criteria for man-machine combinations.

Commanders were required to develop the tactics necessary to prevent damage by hostile weapons, to deplete enemy capability by destruction of hostile weapons and to conserve counter-forces as far as possible. They were faced with from 60 to 96 tracks in the surveillance situation and were provided with a variety of aircraft and missile interceptor weapons. The counter actions the commanders selected were evaluated and implemented and the outcomes were made known to them. The effectiveness of the actions selected was compared to both their potential effectiveness and to a sample of independent and "logical" actions such as might be arrived at by various "idealized" decision making systems.

Summary measures of the commanders' performance are

presented below. Figure 1 summarizes damage assessed in terms of per cent of weapons lost by load and threat complexity level for the two experimental groups, and for cost in terms of weapons expended. It can be seen that Group I (the commanders with the most experimental experience) was generally superior in performance in having sustained less damage than Group II. The latter group, however, showed considerable improvement with limited practice except at the highest loads. Lower damage, in the long run, can only be achieved by a greater use of the weapons available. This often requires the commitment of large numbers of weapons and little or no delay in assignment. The fact that Group I assigned more weapons accounts largely for their superior prevention of damage.

Another performance measure which indicates success in selecting actions is indicated by the number of kills achieved, as reported in Figure 2. If damage alone were considered, an incomplete picture of performance would result since elimination of a small number of critical tracks could minimize damage. Overall efficiency in the tasks required here also calls for a reduction of enemy capability. In performance of this task it may be seen that Group I was more effective in dealing with the threat situation. While Group II shows an ability to "keep up" with the load, they showed more evidence of becoming saturated at the highest loads than the more experienced group.

Figure 3 and 4 compare the actual commanders' performance with the summary performance of three classes of "analytical" or logical solutions to the same decision making problems. The better "idealized" solutions showed somewhat better damage prevention

than the real commanders and killed substantially more of the enemy, but at the expense of nearly total exhaustion of the counter-weapon resources.

The following were the overall findings of this experiment:

1. Substantial damage was prevented by the experimental commanders with the more experienced group showing superior performance.

2. Weapons were well preserved in terms of maintaining a capable posture.

3. Reusable threat vehicles were destroyed to the extent that little capability remained.

4. Successful strategies were derived by the commanders, but ability to verbalize the approach was not fully developed.

5. Track load did not provide the deleterious effect expected; in fact, the most experienced group showed little evidence of leveling off in performance. In addition:

(a) A definite pacing effort was observed, in that, as load increased the commanders increased the rate at which they reacted to the situation.

(b) Ability to sort among threat and weapon categories did not level off in this experiment.

6. Frequent exposure to near-saturation task loads tended to insure optimum performance of the man-machine combinations in threat evaluation and action selection.

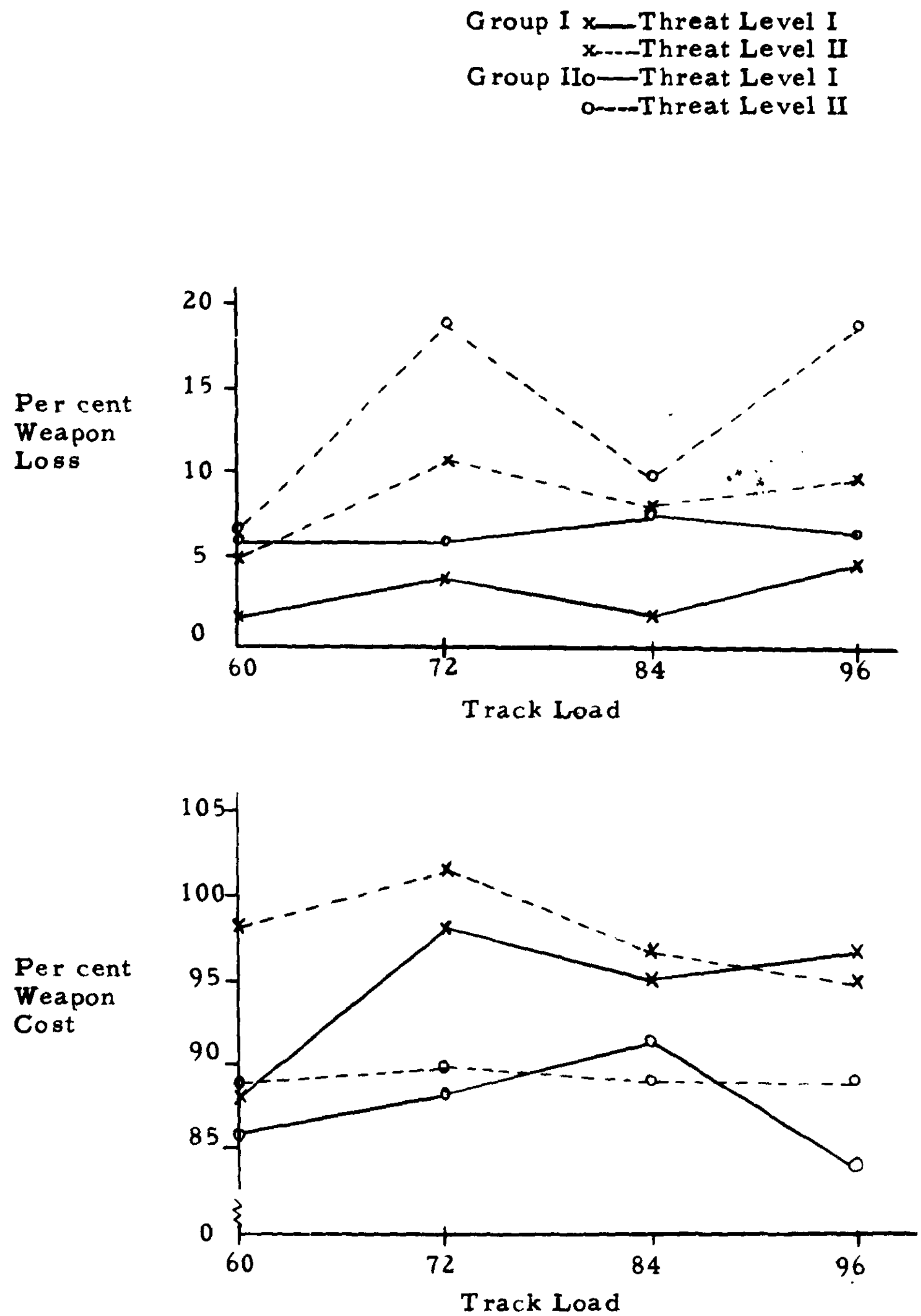


Figure 1. Damage and weapon use as a function of load and threat level for two groups of commanders.

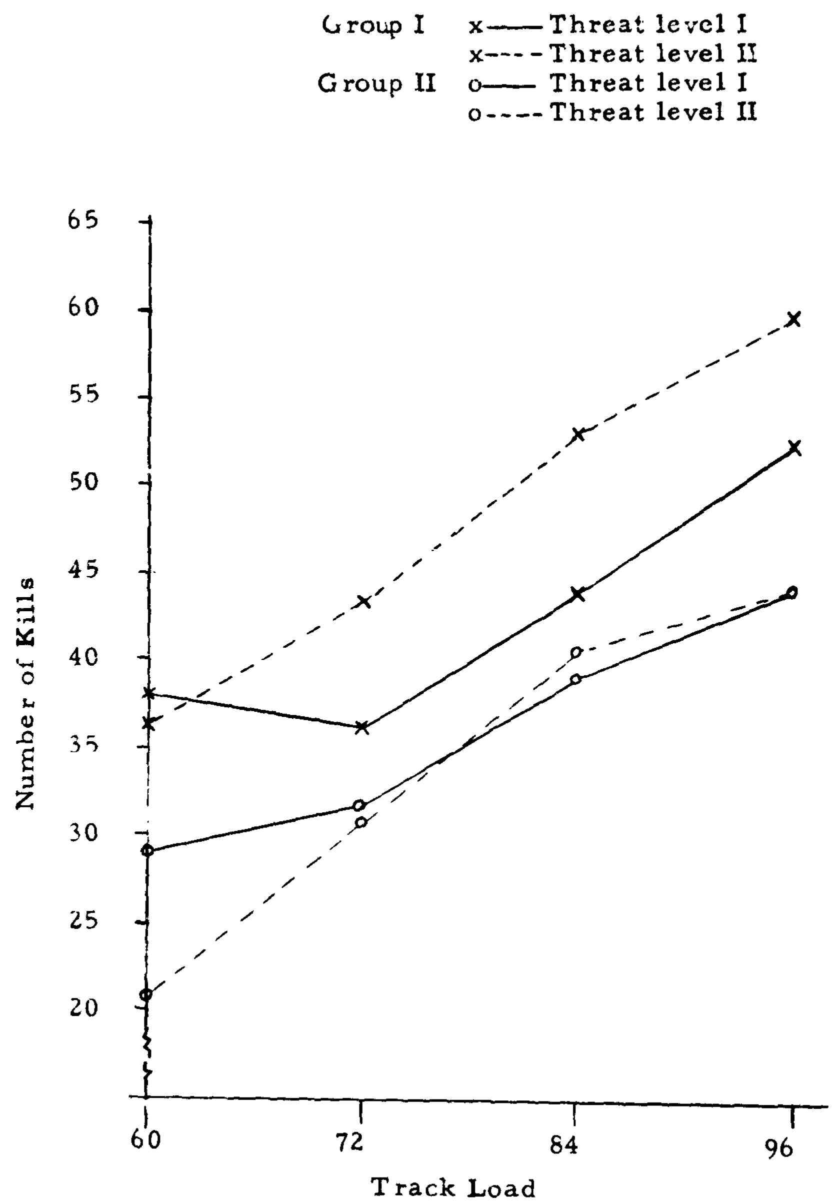


Figure 2. Threats Destroyed as a Function of Load and Threat Level for two Groups of Commanders.

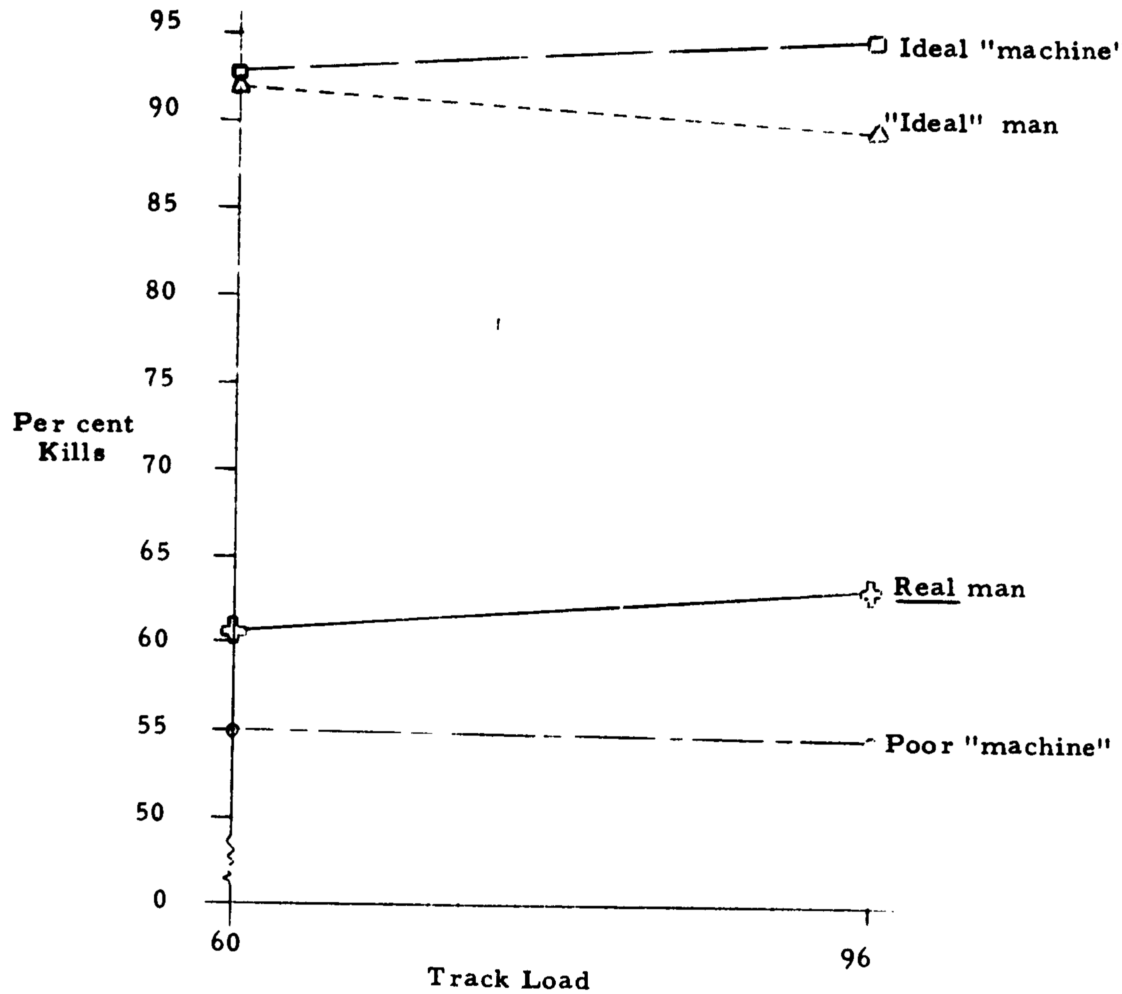


Figure 3. Analytical vs. sample empirical performance: Threats destroyed at two levels of load.

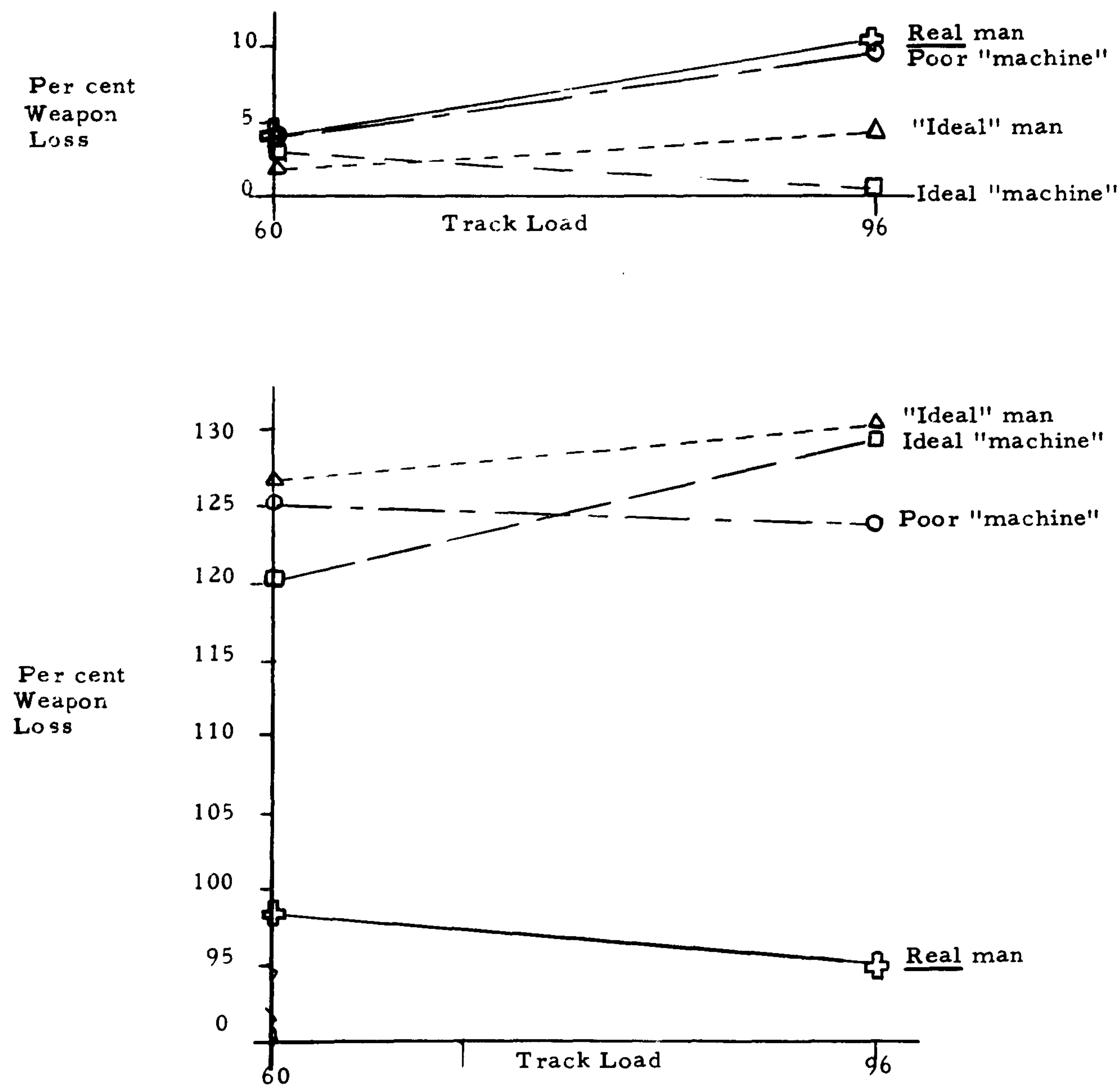


Figure 4. Analytical vs. sample empirical performance: Damage and weapons used at two levels of load.

PROCEDURES

The basic apparatus has been described in detail in previous reports (16, 28). The schematic site layout (Figure 5) and the information flow diagram (Figure 6) provide the essential elements for understanding this study. From the position of the tactical decision-maker, the environment consisted of a "command post" type of facility. The decision-maker was seated at a digital display console on which was displayed the geographic position situation of the aerospace forces (both enemy and friendly) under surveillance. "Targets" or tracks were indicated by spots of light showing on a cathode ray tube screen. A small portion of track history was shown by the persistence of previous track positions. The system cycling time, i.e., the time to update all information stored on the drum to the digital display, was 10 milliseconds, allowing all targets to be viewed without interruption. Track categories were capable of being coded for IFF by dimming, brightening, focussing or defocussing the track spots. Track categories could be selected for display or inhibited by selection of suitable switches. New tracks would "blink" on entry into the situation. This blinking could be inhibited, at time of interrogation with the photo-electric light gun, by depressing a small thumb switch. Tracks could be allowed to remain blinking as a memory aid to indicate that further action was required or action should be delayed. Tracks would reinitiate blinking when identification or other ancillary data changed. Any track could be selectively called up by track number, and when the particular track number was inserted, that

track blip would blink to show its location, while all others would be inhibited from blinking. Upon such a track interrogation, all ancillary information associated with the track (IFF, speed, altitude, category, and personal identity coding) would be read out in alphanumeric form on a small display panel located on the top of the digital display. The basic track position situation and identifying data were supplied to the system from digital recordings on magnetic tape, routed through a selective device by which different track block combinations could be displayed. Additional details may be found in Appendices I and II.

In addition to the electronically generated displays described above, the decision-maker had other display sources to consider for the solution of each problem. The CRT had a skeleton diagram overlaid on it, showing the location of the friendly weapon sites. This bounded a surveillance area of 300 by 300 nautical miles. In addition, two weapon status boards were located directly behind the digital display console (a schematic drawing of which is in Appendix I). The status display boards in this experiment were manually posted by two airman technicians behind the edge-lit lucite board. An action log was maintained for the decision-maker by another airman technician who recorded each action as it occurred and made this information available on call to the commander. In addition the airman technician notified the commander immediately of priority outcomes (missed-intercept data). The remainder of the equipment mainly consisted of interior communication links (a modified AN/GTA-6), pencils and paper, and a digital clock.

The overall operating procedure is best described by describing

portions of an operation step by step in time sequence.

1. The tape recorded track situation data were fed into the digital communications system, thence to a drum store, and thence to the situation display. The first targets appeared at problem time zero. Weapon status at the onset of each mission is shown in Appendix I.

2. The tactical commanders first duty was to interrogate the first tracks one at a time. On the basis of position, identification, kind, speed, etc., he would act against each target.

3. The action selected consisted of the track number to be attacked, the weapon kind, the site from which it was to be drawn, the armament type and the number of such weapons. The mode of employment was assumed to be that of a single flight group. There were no grouped "raids" or raid assignment capabilities, as such, in this experiment.

4. The action selected was simultaneously recorded, together with the time it was selected, by the commanders' airman technician and by the "scramble clerk" at the referee station.

5. The scramble clerk passed the slip on which he had recorded the action data to the inventory clerk. Appropriate deductions from inventory were communicated to the weapon status board where the board keepers made the necessary changes.

6. The inventory clerk passed the assignment to one of three action referees (one for missile assignments and the other two for aircraft assignments). The referee then evaluated the action against a scoring sheet containing the distributions of "kills" and "misses"

(for each track) along with outcome time data. A sample referee sheet with detailed explanations may be found in Appendix II.

7. The action outcome, if a kill, was passed to the closeout technician who would:

(a) cause the track in question to be removed from the system at the specified time (this time was also preplanned and was a function of the intercept time which in turn depended upon the speed of the weapon assigned and the distance-to-go at scramble time) and,

(b) transmit the outcome information to the commander (via the commanders technician) at the outcome time.

8. The outcome, if not a kill, was also transmitted to the commander (the commanders' technician gave the commander the outcome as a priority message) at the outcome time, but without closing the track out of the system.

9. Each action referee also had a running record, by time, of all preprogrammed potential damage which could be inflicted by any track. If a track capable of inflicting damage was killed prior to causing the damage, no losses were assessed. Otherwise, the potential weapon site was assessed for possible damage, and losses, if any, were posted on the weapon status boards. Such weapons lost were removed permanently from the inventory of that site.

Experimental missions had a duration of 45 minutes for all track situations presented. The details of the experimental plan may be found in Appendix II. The commanders (or tactical decision-makers) in this experiment were all First Lieutenants and Captains with extensive

AC&W experience in operational sites and in the Experimental Sage Sector as well. They were briefed in detail on the purposes of the experiment (except for such knowledge of experimental conditions as would vitiate the results if foreknown) and on their duties (cf Appendix I). Thev were also given an intelligence briefing prior to each mission and the opportunity to review any of the ground rules or operating conditions or procedures. Numerous practice problems were run with each commander prior to the collection of the data described below (cf Appendix II).

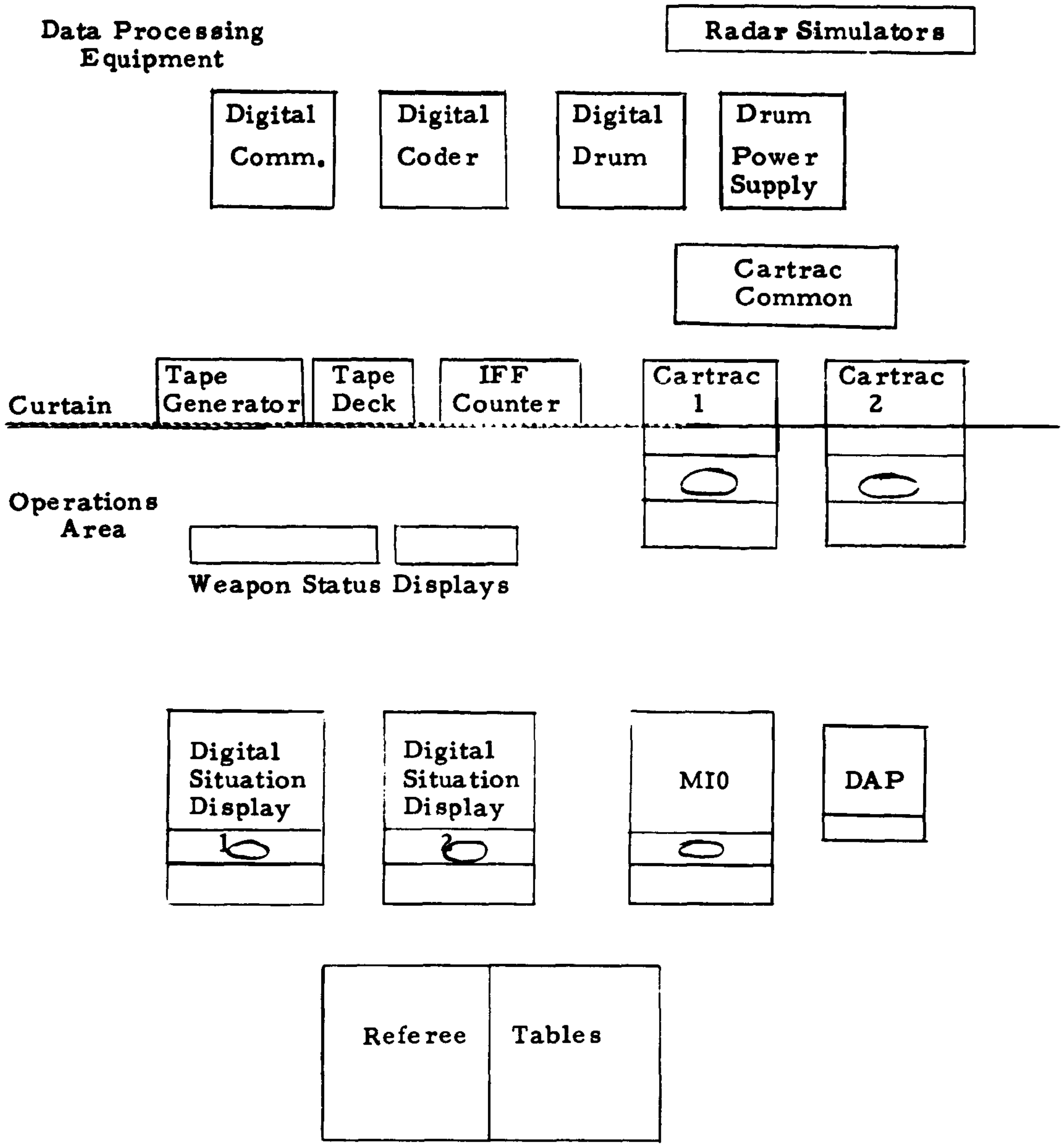


Figure 5. Equipment Layout

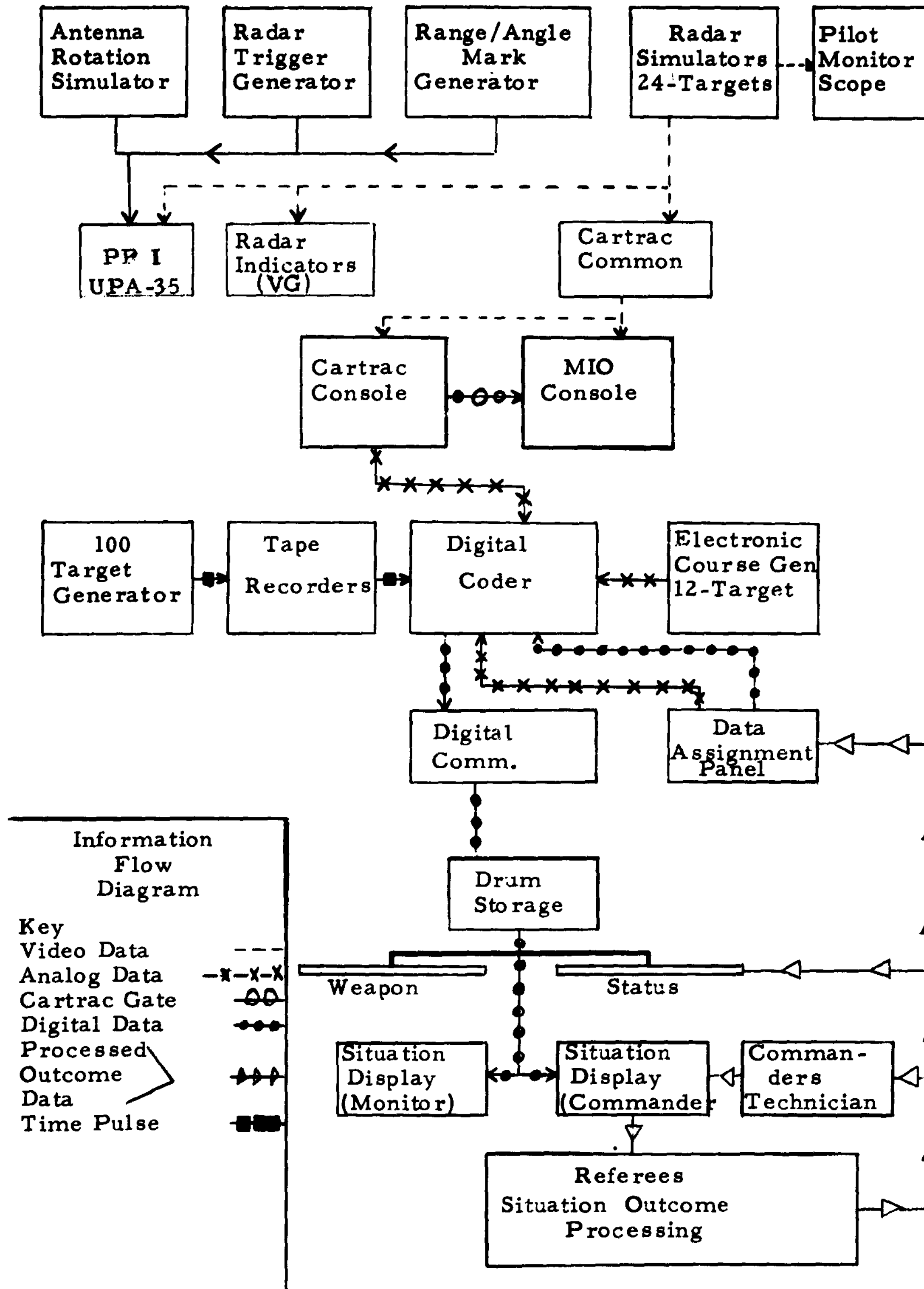


Figure 6. Information Flow Diagram

RESULTS AND DISCUSSION

Since this research focused on the adequacy of decision making by executives, the primary datum was the record of action taken against each of the total of approximately 9,400 tracks. Specifically, for each track, the kind of action taken, the time it was selected, and the number of actions were all recorded. In subsequent analyses of these recordings, two particular measures of decision adequacy--delay in decision, which was defined as time from track appearance to action order, and correctness of decision, defined as appropriateness in application of action criteria--were derived. These data will be reported and discussed with the goal of specifying the adequacy of decision performance, under varying conditions of load, with regard particularly to the fourfold task that had been given the executive. This mission was the classic one assigned commanders from time immemorial: (1) to defend his forces (minimize damage to the weapon areas); (2) to damage the enemy (maximize number of threat vehicles destroyed); (3) to conserve counter weapons so as to consume a minimum of forces consistent with objectives (1) and (2), above; and (4) to develop his own strategy under the constraints imposed by the ground rules (cf Appendix I for details).

From the post-mission debriefing, additional records were made. Specific items toward which this inquiry was directed were whether or not he, the commander, was aware of his success or failure in coping with each mission, whether or not he could evaluate

the adequacy of the advance intelligence-briefing, and his evaluation of the adequacy of his weapon inventory.

The first results to be presented, below, specify for the experimental groups the average rates of events occurring versus actions selected, outcomes achieved, commanders' errors in data processing and commanders' awareness of their performance. The subject's results are also contrasted against analytical measures of performance. Finally, comparisons of individual subject's performance against critical features internal to each experimental problem are summarized in order to consider implications for decision making as a process.

I. GROUP PERFORMANCE MEASURES

A. Analysis of weapon selection performance.

In the following graphs, direct comparisons between the two experimental groups by track load, threat level, and alternative site configurations, for the experimental variables under consideration, are shown. Group I performance usually is indicated by the top and middle sets of graphs; the lower set of the two indicates the more complex threat level. The bottom set of graphs shows the Group II, or less experienced group, performance for both levels of threat complexity.

1. Threat processing

Figure 7 depicts the total numbers of tracks which had entered the situation display at the end of each five minutes period, the total numbers against which at least one action had been taken and

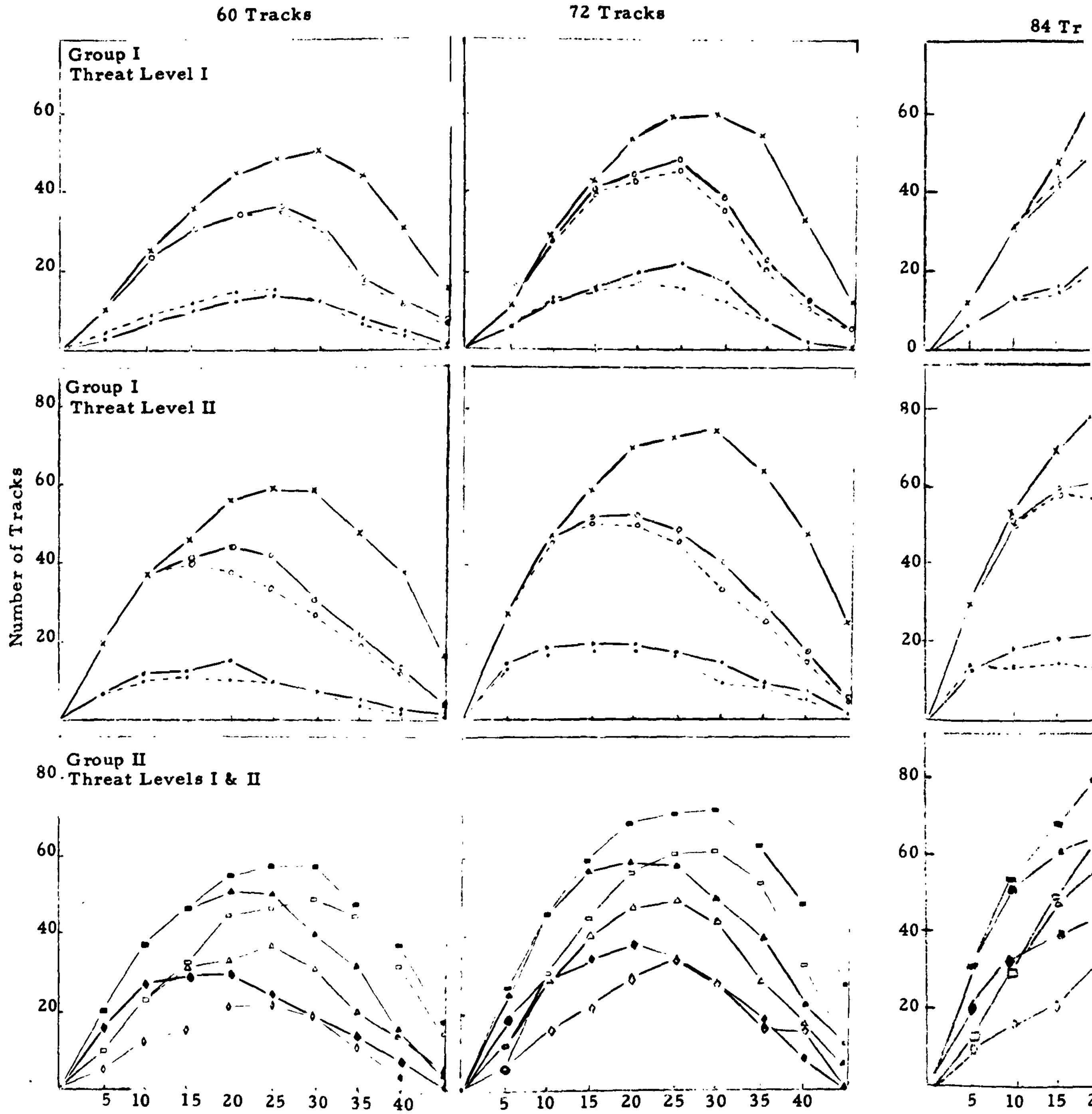
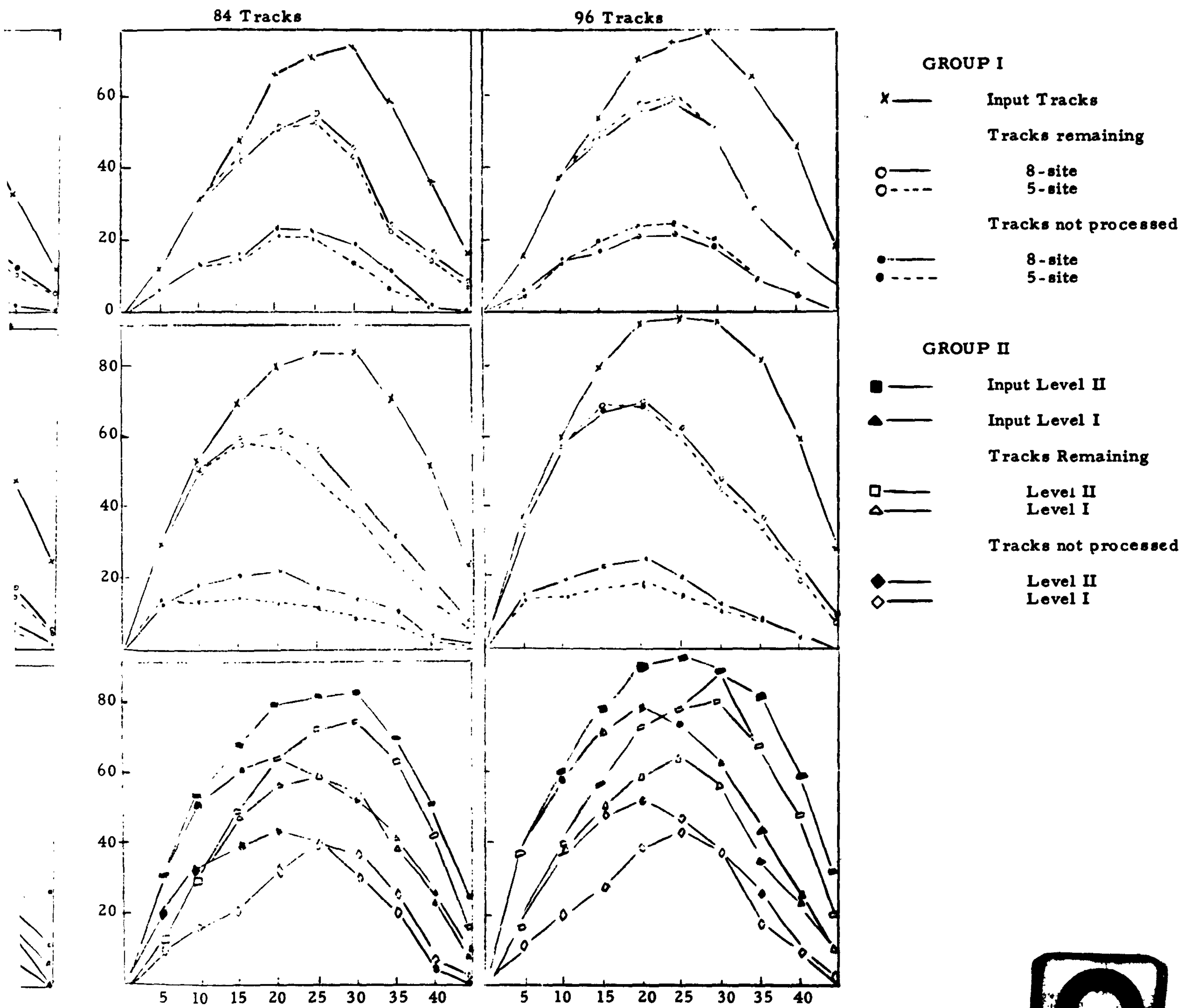


Figure 7. Target track inputs, tracks remaining, and tracks not processed, by time in problem.



84 Tracks
96 Tracks
GROUP I
Input Tracks
Tracks remaining
8-site
5-site
Tracks not processed
8-site
5-site
GROUP II
Input Level II
Input Level I
Tracks Remaining
Level II
Level I
Tracks not processed
Level II
Level I

the numbers against which no action had been taken. These data are plotted as functions of the load and general threat l evel for GroupII plus the defensive site configuration for Group II plus the defensive site configuration for Group I commanders. Each plot represents the number of tracks of a class still present in the situation. The plots of "tracks remaining" include both processed (i.e., those acted against) and unprocessed tracks. The difference between the "input tracks" and "tracks remaining" reflects the number of kills or successful selected actions. Particularly worthy of note in this figure is the difference in performance between the main experimental group (I), more experienced, and the second group, (II), that received the eight-site configurations only. This difference can be seen particularly for kill rate achieved, and also in the disparity of the number of tracks not processed. The backlog of unassigned tracks increases with load and is much flatter over time for Group I. The less experienced group as might be expected, allows it to build-up faster and remain longer. There is, however, very little difference in either kill rate or backlog between five and eight sites, though both seem most frequently lower for five sites. Further, threat level II seems to affect Group II much more severely than Group I (as might be expected due to amount of practice). In interpreting these figures it should be recalled that load built up to a peak at the twenty to twenty-five minute interval and then diminished slowly until the end of each problem at forty-five minutes. No track close-out of any value was achieved before problem time ten; this was due to the tendency to assign on the initial tracks with fighter-interceptors, as will be shown later.

2. Weapon assignment rate

The rates at which both missiles and aircraft interceptors were assigned are indicated, below, in Figure 8. Both experimental groups reacted with an increasing rate of response as load increased, with Group I showing the higher response rate.

The Commanders were instructed to derive their own solutions to these problems, and this figure indicates very strongly that the approach that was adopted by both groups was an increasing use of fighter interceptors early in each problem, and the use of missiles later when problem load was high. The quicker feedback time of the missiles permitted this weapon to be used as backup, i.e., to eliminate targets where an initial aircraft assignment had failed, or to kill quickly any target appearing during the later stages of the problem, which constituted the "loaded" interval. Note that the assignment behavior of Group II does not show much early economy of missiles except as load 96. This figure and the indicated kill rates from Figure 7 indicate that essentially the problems were dealt with in the first 35 minutes or so of problem life, with an adequacy such that few assignments remained to be generated at the end of each problem. Assignment of weapons from five, as opposed to eight, sites appear to be accomplished equally well, with the exception of the highest two loads at threat level two for Group I. Here a slight difference is noted for a short interval of time in aircraft assignments and also in missiles, but at only the highest track load.

Two interpretations may be advanced to account for the increase

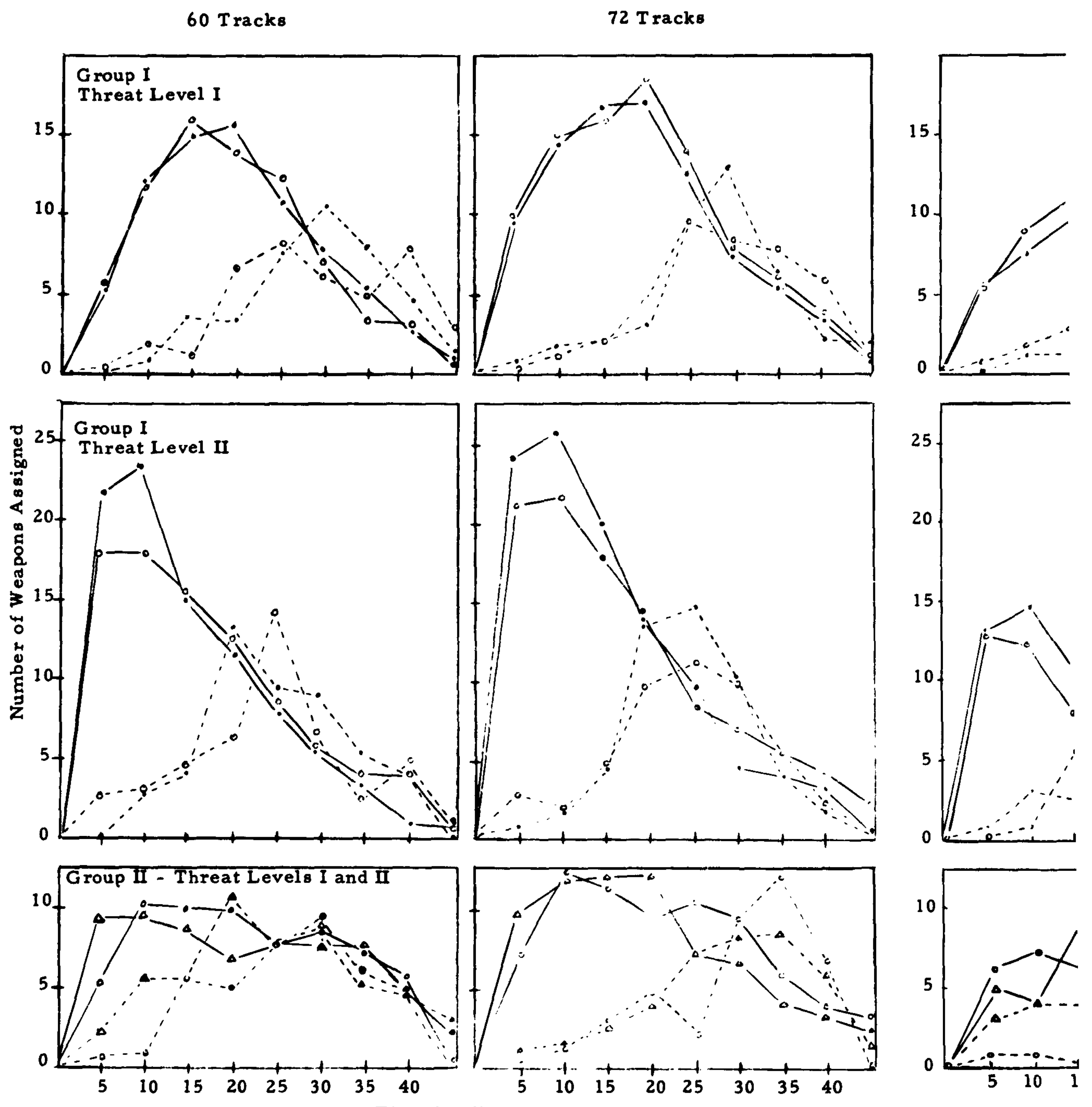
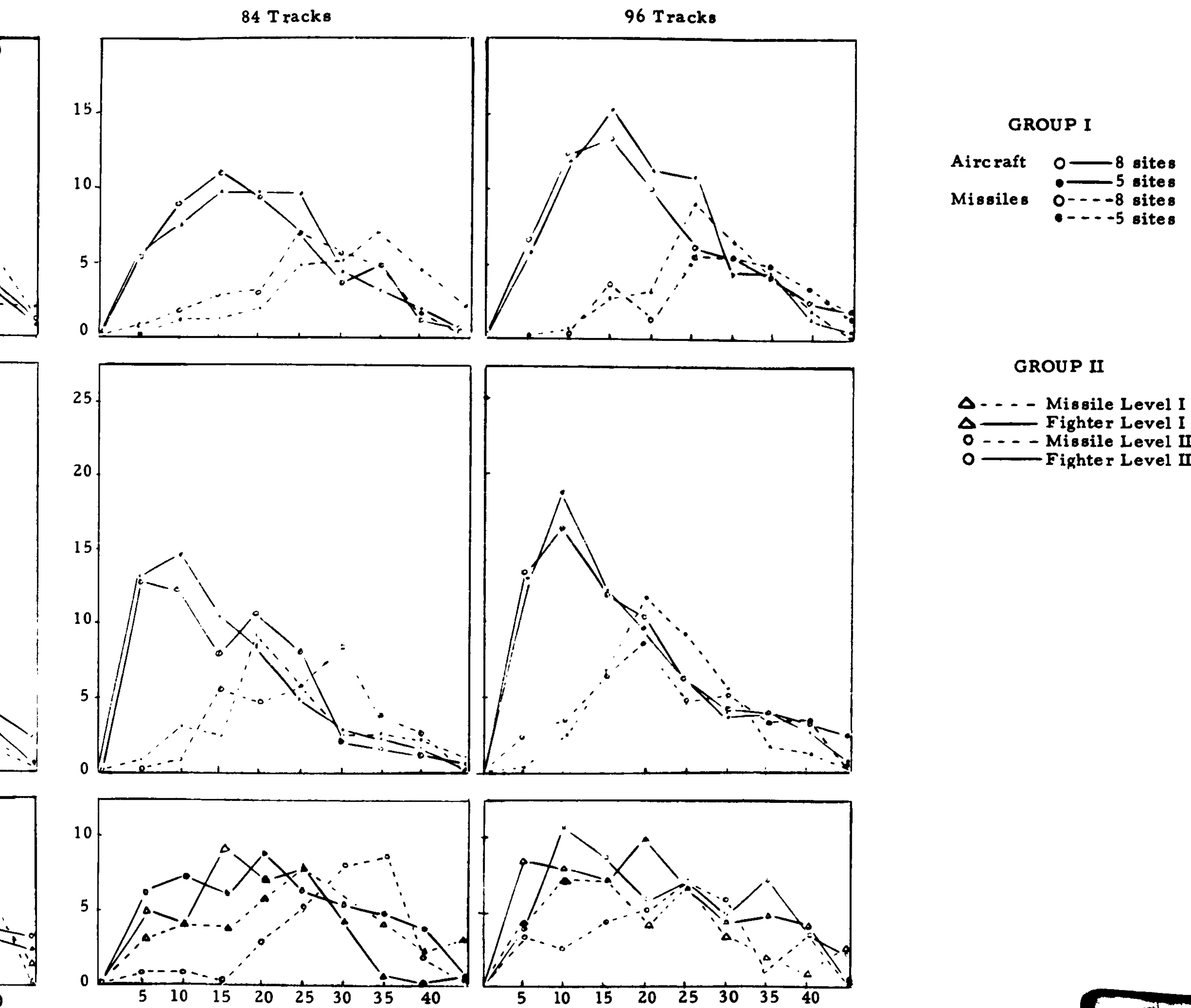


Figure 8. Weapon assignment rates for 5 vs 8 sites and missiles vs aircraft


84 Tracks
96 Tracks
GROUP I
Aircraft o——8 sites
•——5 sites
Missiles o----8 sites
•----5 sites
GROUP II
△---- Missile Level I
△—— Fighter Level I
o ---- Missile Level II
o —— Fighter Level II
0
5
10
15
20
25
30
35
40

in the assignment rate under increasing threat load: (1) An increased rate of response due to increased awareness of the threat, or (2) a pacing effect of the stimulus inputs either due to the way the problems were designed or to some general property of behavior in the face of increasing load situations. The data presented in Figure 9 appears to support choice of the latter interpretation.

3. <u>Weapon assignment rate by threat class</u>

Figure 9, below, shows the rates at which weapons were assigned against the three threat categories capable of inflicting damage: bomber, fighter-bomber and fighter inputs. Only data on Group I, for threat level two, will be discussed here. This figure supports a pacing-by-load concept, i.e., the assignment rate increases as a direct function of load. It is notable that this assignment rate is highest for fighter-type threats, indicating that the commanders were reacting more to increase in number of tracks than to specific discriminations of the extent of the threat implied by a particular track. The second group of commanders was impeded more by the increasing load, in that their rate increases was consideraly lower, (these data are not shown here).

High assignment rates on fighters are due, in part, to the nature of their entry into the problems. Because they are small vehicles, and hence, would present less frequent radar returns, many were programmed to appear for the first time near a weapon site. The experimenters were able to observe that when load was high many

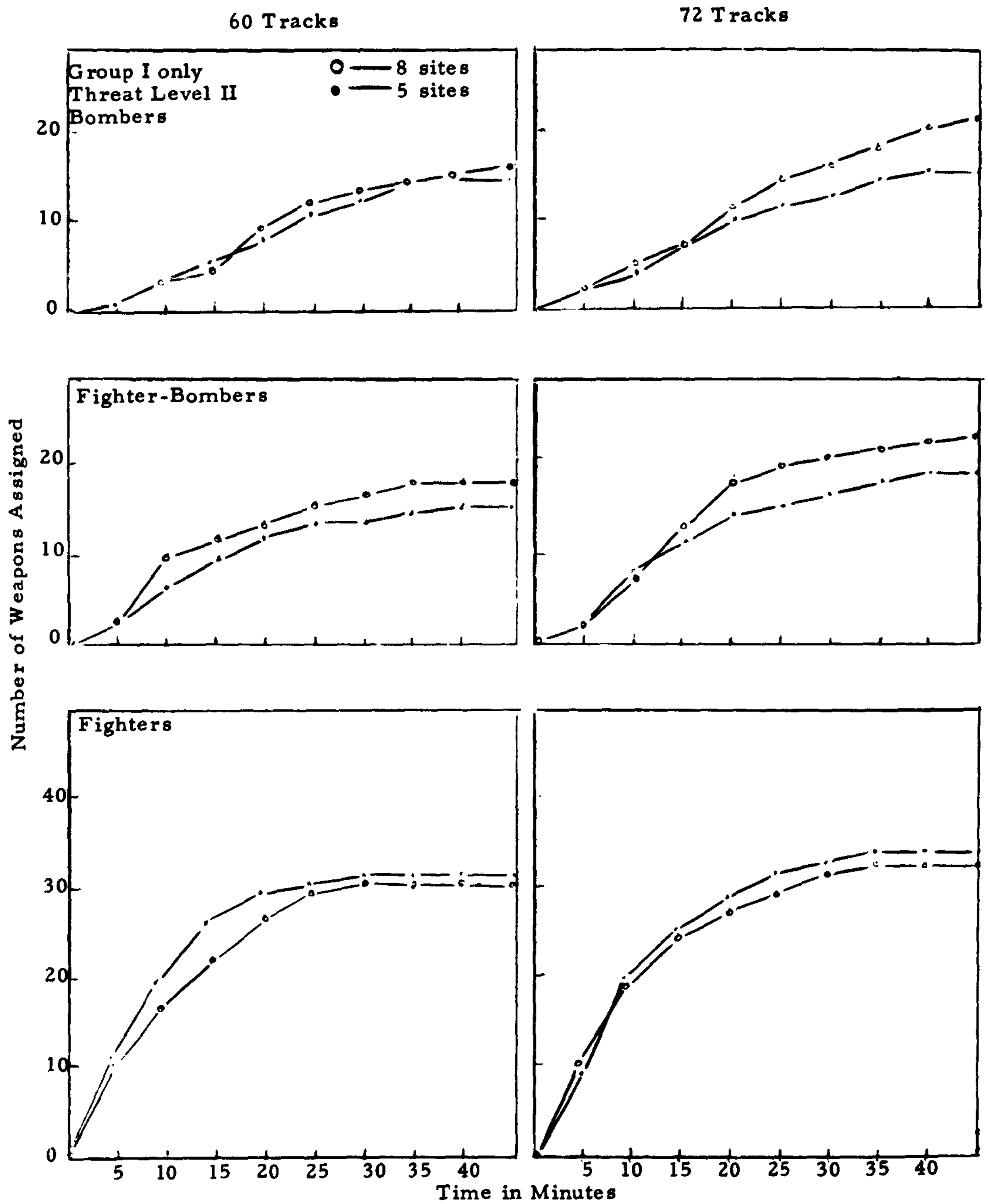
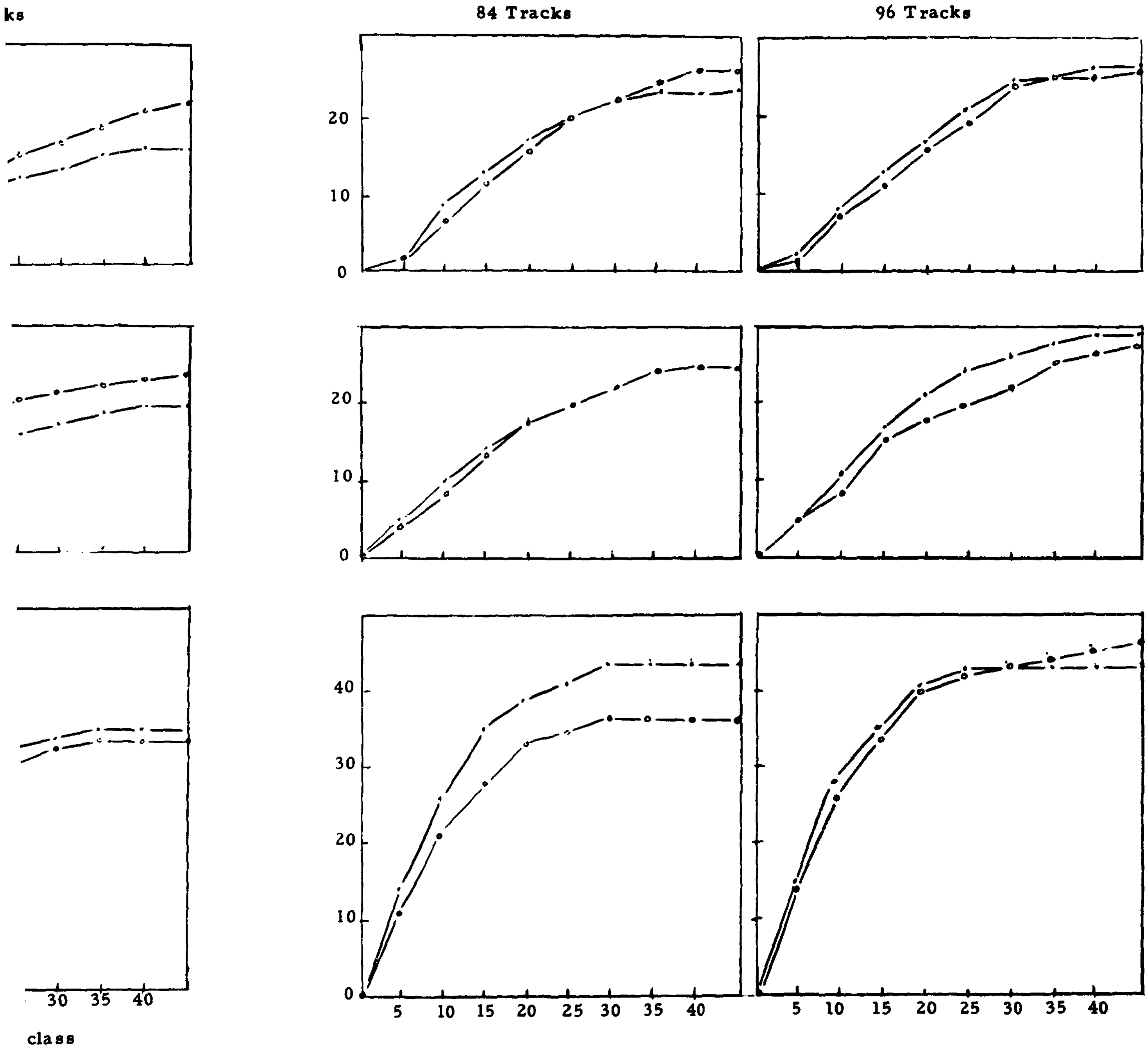


Figure 9. Weapon Assignment rates by threat class



ks
84 Tracks
96 Tracks
20
10
0
20
10
0
40
30
20
10
0
30 35 40
5 10 15 20 25 30 35 40
5 10 15 20 25 30 35 40
class

subjects tended to give priority to threat tracks that were approaching and friendly sites. Fighers appearing here may have had, in effect, a nuisance value that forced the commander to react against them. This will be examined more fully under the discussion of delay times, below. With regard to assigning fromfive versus from eight sites, the figure indicates, again, about equal facility on the part of the commanders.

4. Weapon assignment against "real" vs. "apparent" threat

While Figure 8, above, indicated the weapon assignment rates against perceived threat in general, Figure 10 compares the weapon assignments against the "reals", or tracks with damage potential, versus weapon assignments against the "apparent" threats, that look threatening due to their labels (e.g., Foe Bomber) and the general direction that they are heading, but which do not possess actual damage potential. The uppermost set of graphs indicates the "real" threat input rate (solid line) and the "apparent" threat (dotted line). The middle set of graphs indicates the assignment rate for missiles (solid line) and aircraft (dotted line), for both site modes (dot equals five-site, open circle equals eight-site), for Group I. The bottom set of graphs indicates the comparable assignment rates for Group II. The graphs on the left side of each page represent threat level I, and those on the right side threat level II. Note that the assignment rate for "apparent" threat is considerably higher than for "real" threat tracks. There are actually more of the former class, and the ratio between apparent and real threats

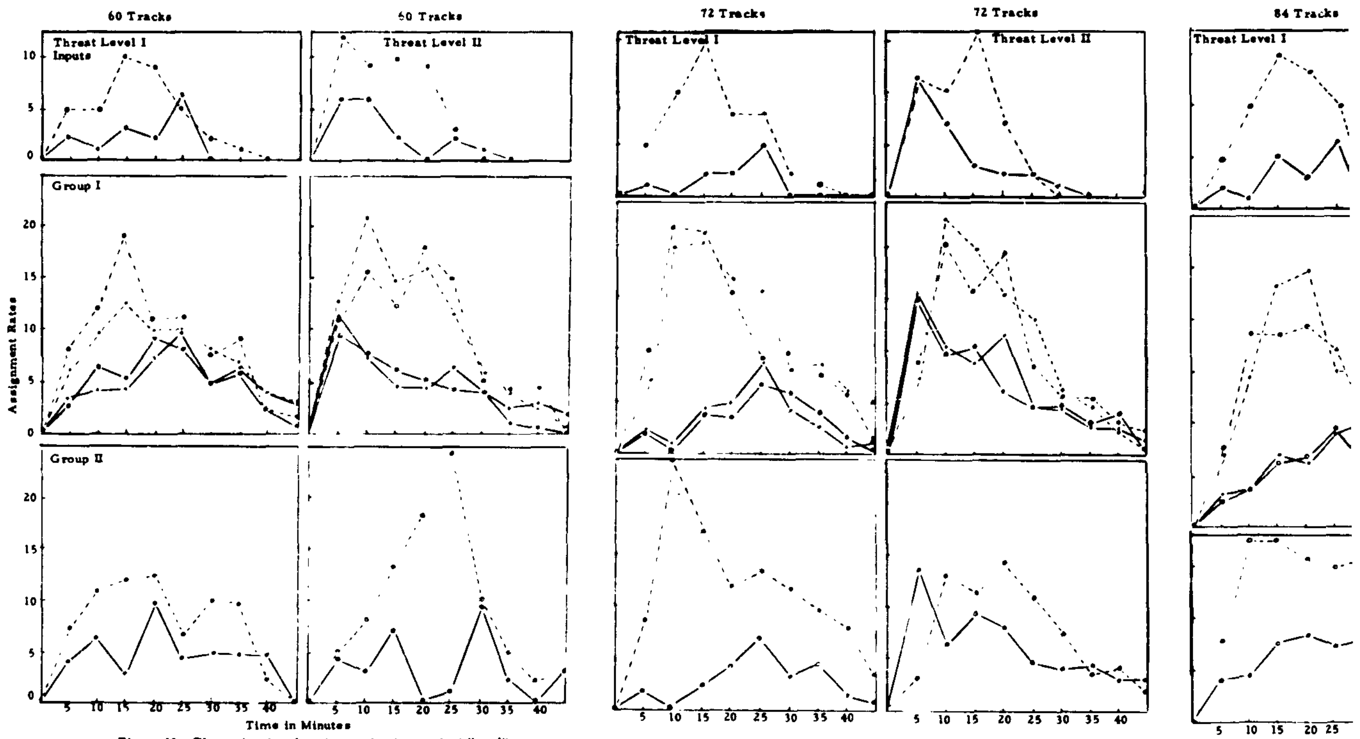
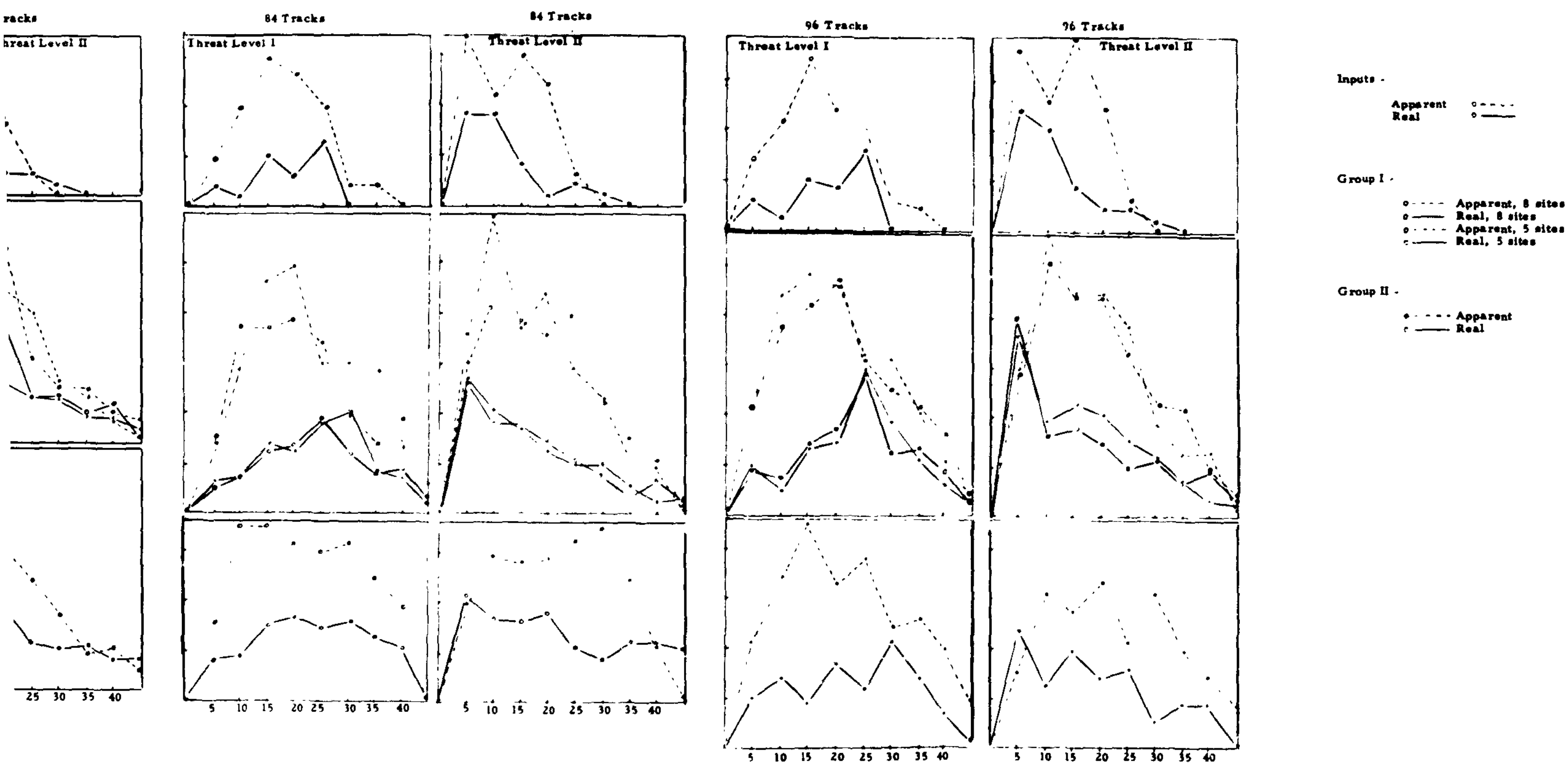


Figure 10. Threat input and assignment rates against "real" vs. "apparent" threat tracks, Groups I and II.



racks
hreat Level II
84 Tracks
Threat Level I
84 Tracks
Threat Level II
96 Tracks
Threat Level I
96 Tracks
Threat Level II
5 10 15 20 25 30 35 40
Inputs -
Apparent
Real
Group I -
Apparent, 8 sites
Real, 8 sites
Apparent, 5 sites
Real, 5 sites
Group II -
Apparent
Real

and that between the assignments against them are about the same.

The evidence of pacing by "number of tracks" for both groups again is apparent. Group II, however, again shows some increased delay in processing all tracks.

The fact that a track enters the situation initiates a new cycle in the command function. Each such entering track first must be evaluated for possible threat. This evaluation is not automatic; one reason for this being that the target of ahostile track may not be obvious for quite some amount of track life. Assignments must be committed early, but the outcome at this time is uncertain. Neither man nor a computer acting in man's place can go beyond an extrapolation based on past history of the displayed hostile track when it comes to prediction of the probable target, if the rule is that the decision is to be based solely on track data. Where little additional information is presented, the decision maker must assume that all threats are valid, thus, he must take appropriate action on all of them.

5. Weapons assigned per kill

If, over a series of simulated battles, the commander developed skill in action selection, one would expect to see him increasing the efficiency of employment of his weaponry. Since the action outcomes are probabilistic in nature (ranging from .1 to .999), the number of weapons to achieve a kill must average more than one. Figure 11 indicates the number of weapons assigned, including some that have been mis-matches or too late assignments for each hostile track killed. The uppermost graphs present data for threat level I

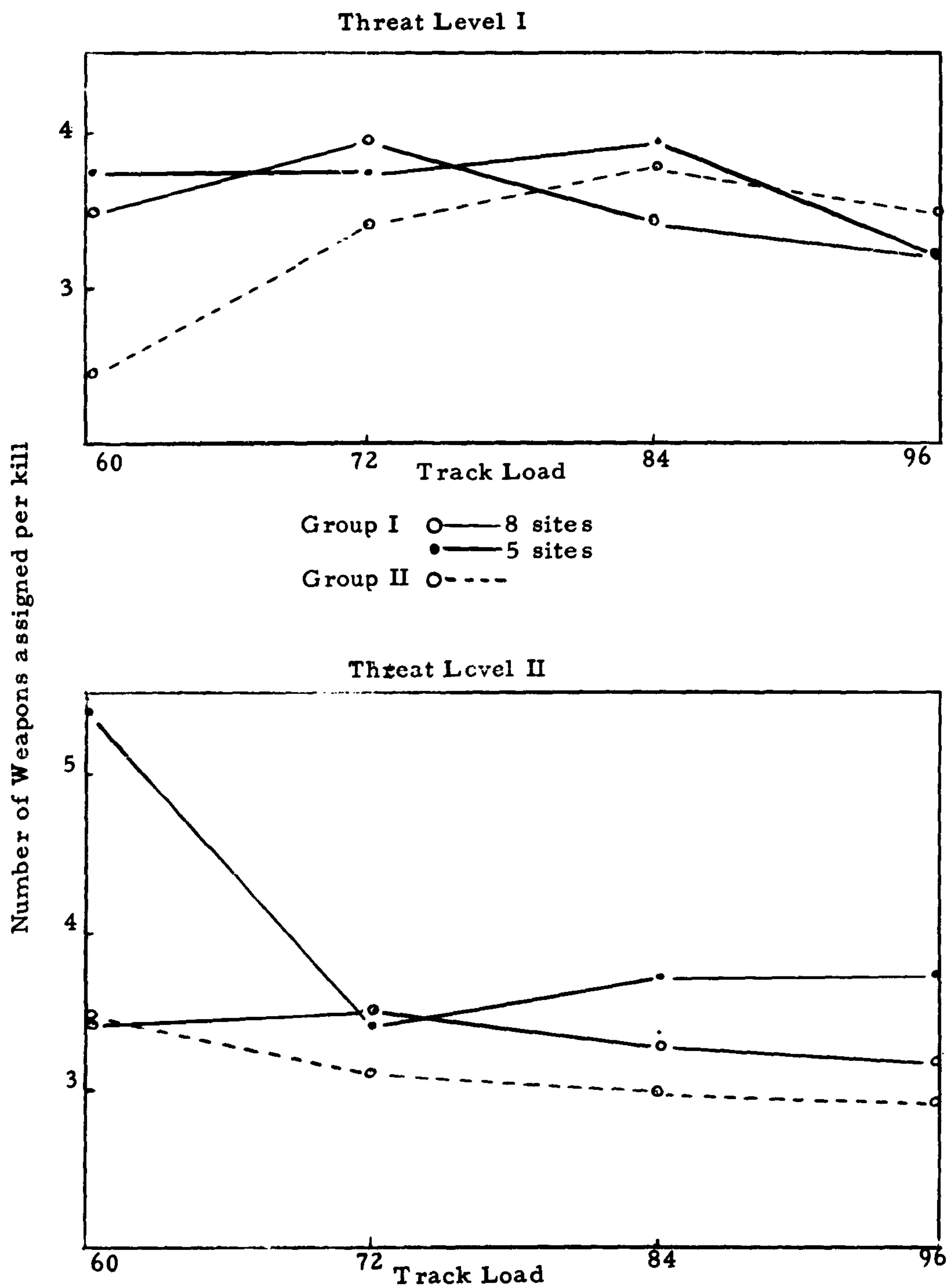


Figure 11. Weapons assigned per kill

and indicates that more weapons were assigned at this level than at level II. Both experimental groups tend to perform alike in that they regress toward a three-on-one weapon assignment per kill.

6. Weapon usage rate by interceptor class

The commander had available for assignment four levels of interceptor capability plus several varities of armament. Hence, the data may be analyzed to determine whether or not each interceptor performance level was utilized systematically throughout the experiment. Further, it may be asked, do these rates of assignment of the alternative interceptors change as a function of problem complexity and load level? Finally, did the commanders make best use of lowest performance level interceptors, (red class) which, because of their location at forward and vulnerable sites, should be utilized rapidly, before the liklihood of their being lost to enemy action becomes too great? Figures12a and 12b summarize the use of these different performance classes by Group I and II, respectively.

It is apparent from the figures that the missiles are used extensively by both groups, but Group II was more prodigal with this weapon class. In fact, the extremely high missile use at the highest loads by both groups at both levels is further evidence for a "pressure-of-load" hypothesis. Group I tended to use the missiles at a faster rate during the heavy load portion of the problems, especially for the five-site configurations. The red class aircraft were

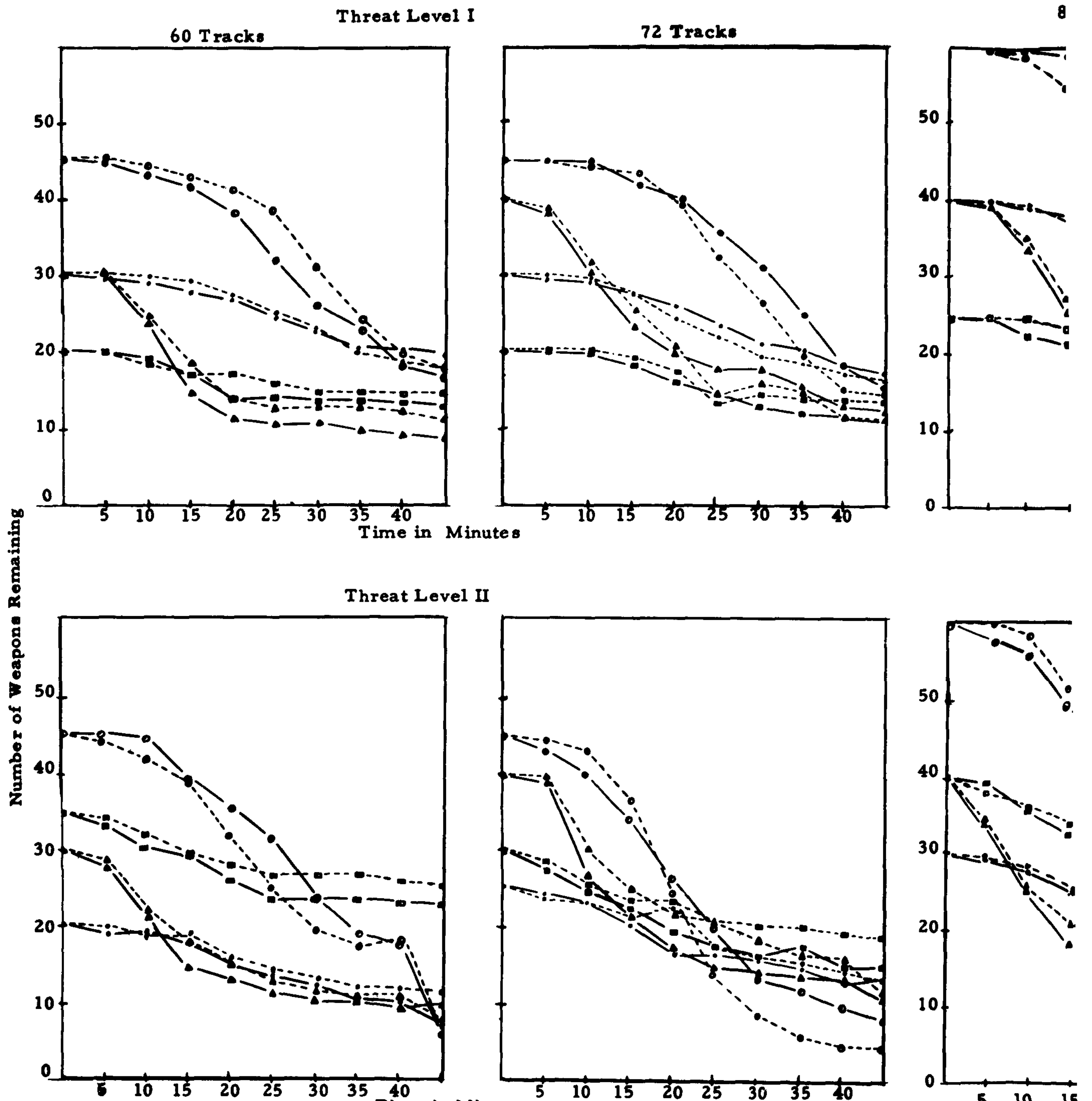
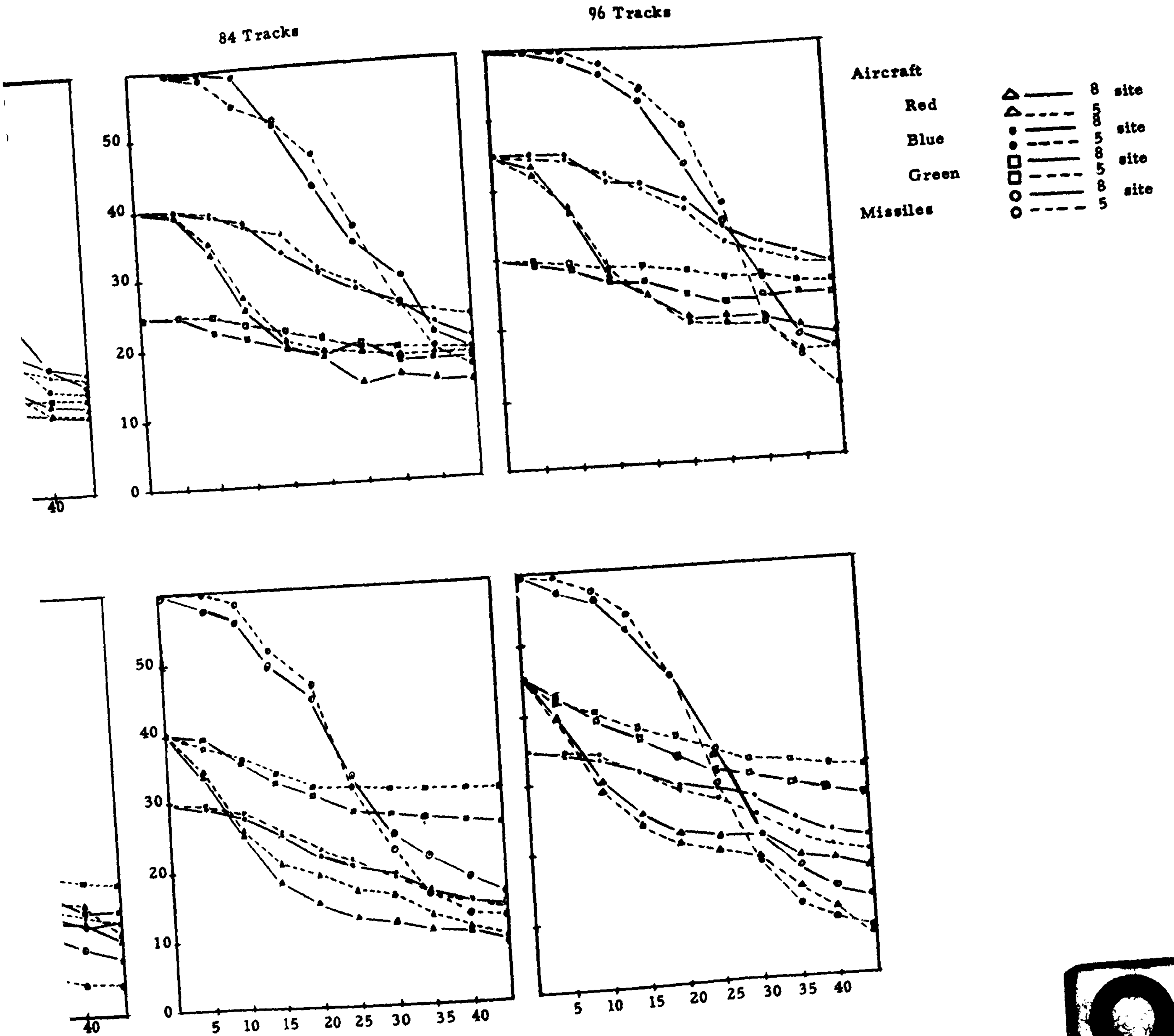


Figure 12a. Number of weapons remaining in inventory for Group I Commanders.



84 Tracks
96 Tracks
Aircraft
Red
Blue
Green
Missiles
8 site
5
8 site
5
8 site
5
8 site
5
0
10
20
30
40
50
5
10
15
20
25
30
35
40

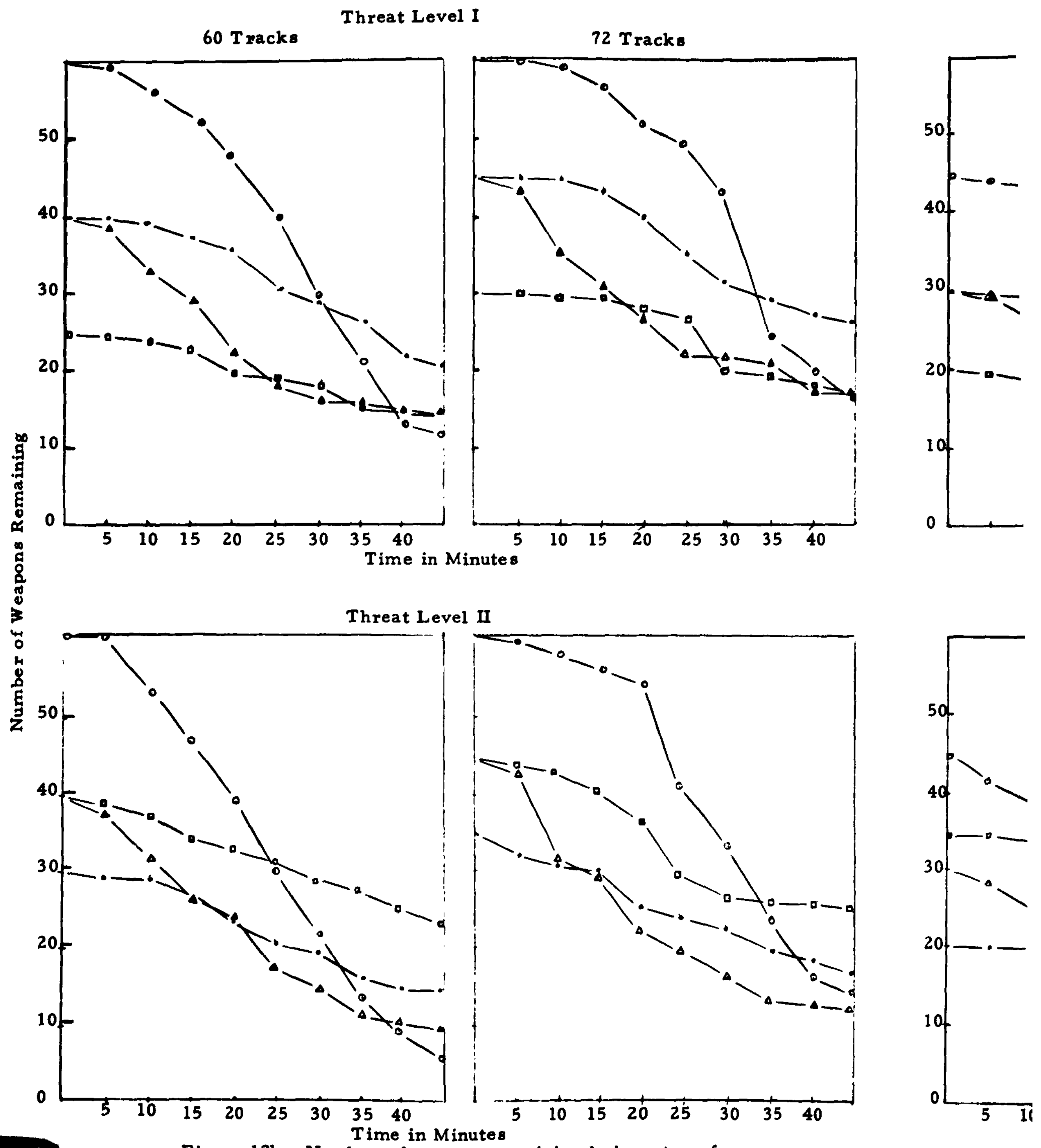
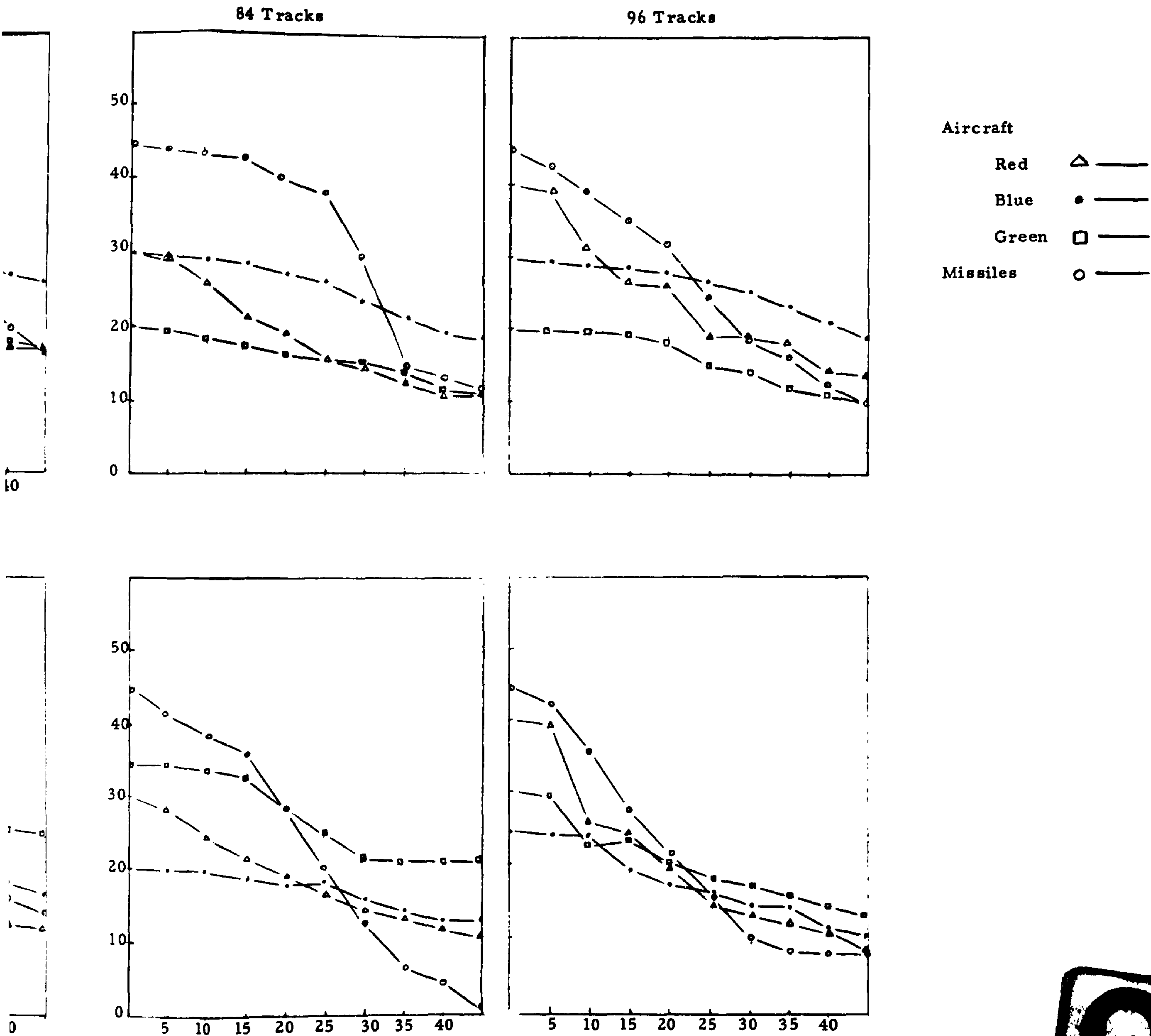


Figure 12b. Number of weapon remaining in inventory for Group II Commanders.


84 Tracks
96 Tracks
Aircraft
Red
Blue
Green
Missiles
0
10
20
30
40
50
5
10
15
20
25
30
35
40

employed as early as possible, taking into account that the matching criteria must be met by having appropriate tracks available, to obtain most of the capability from this class. The second dip in this function at the highest load indicates that many fighers returned from the initial mission early enough to go through the rearming and refueling cycle and be assigned again. Blue class interceptors were used steadily throughout the missions as they were intended to be used (they could stay airborne and had ample stores to run repeated intercepts), but the Green class interceptors tend to be used less frequently. While they could kill the highest performance threat, apparently the commander desired the shorter feedback time associated with missiles. Both groups of commanders tended to expend their missiles, while retaining a higher percentage of fighter-interceptors.

7. Average intercept times

As a sub-task the commander was instructed to achieve intercepts or kills as quickly as possible, consistent with what he believed to be an appropriate action strategy. Following this dictum would tend to reduce the overall work load, and give the decision maker more time to consider additional necessary actions, both of the initial and reassignment types. Particularly, the commander would have more time to consider additional threats with a view toward identifying tracks suitable for intercept by Red and Green class fighters. Early assignments of these fighters was specially important though not, of course, at the expense of appropriate assignment, because timeliness would permit RTB, rearming and refueling, and an early

return to active inventory. If, however, these fighters were scrambled on remote tracks, a minimum intercept time could not be achieved, and they would not be able to go through the refitting cycle in time to be employed again during the mission.

Figure 13 indicates the average intercept time, cumulated over each five-minute interval, for both experimental groups. It is to be noted that there were no kills achieved during the first five-minutes of problem time and usually none were achieved during the second five-minutes earlier. Group I achieved about the same intercept time distributions across the various loads, except at the level of 96 tracks, where a very slight increase in time is shown. There are no marked differences shown for Group I between different threat levels or alternative site configurations. The trend toward shorter intercept times later in the problem probably was due to the fact that incoming, most tracks were much nearer the sites from which weapons were scrambled by the time intercepts were achieved. Group II shows, in general, the same trends. Those commanders appear to have selected shorter intercept times, but this may have been due to inability to assign as rapidly as did members of Group I. (This point will be discussed further under action delay times). Group II appears to have achieved slightly shorter intercept times for fighter assignments against threat level I, than was the case for threat level II.

8. <u>Weapon selection time delays</u>

As the overall load on the commander increases, we would expect increasing delays in responding to the threat inputs.

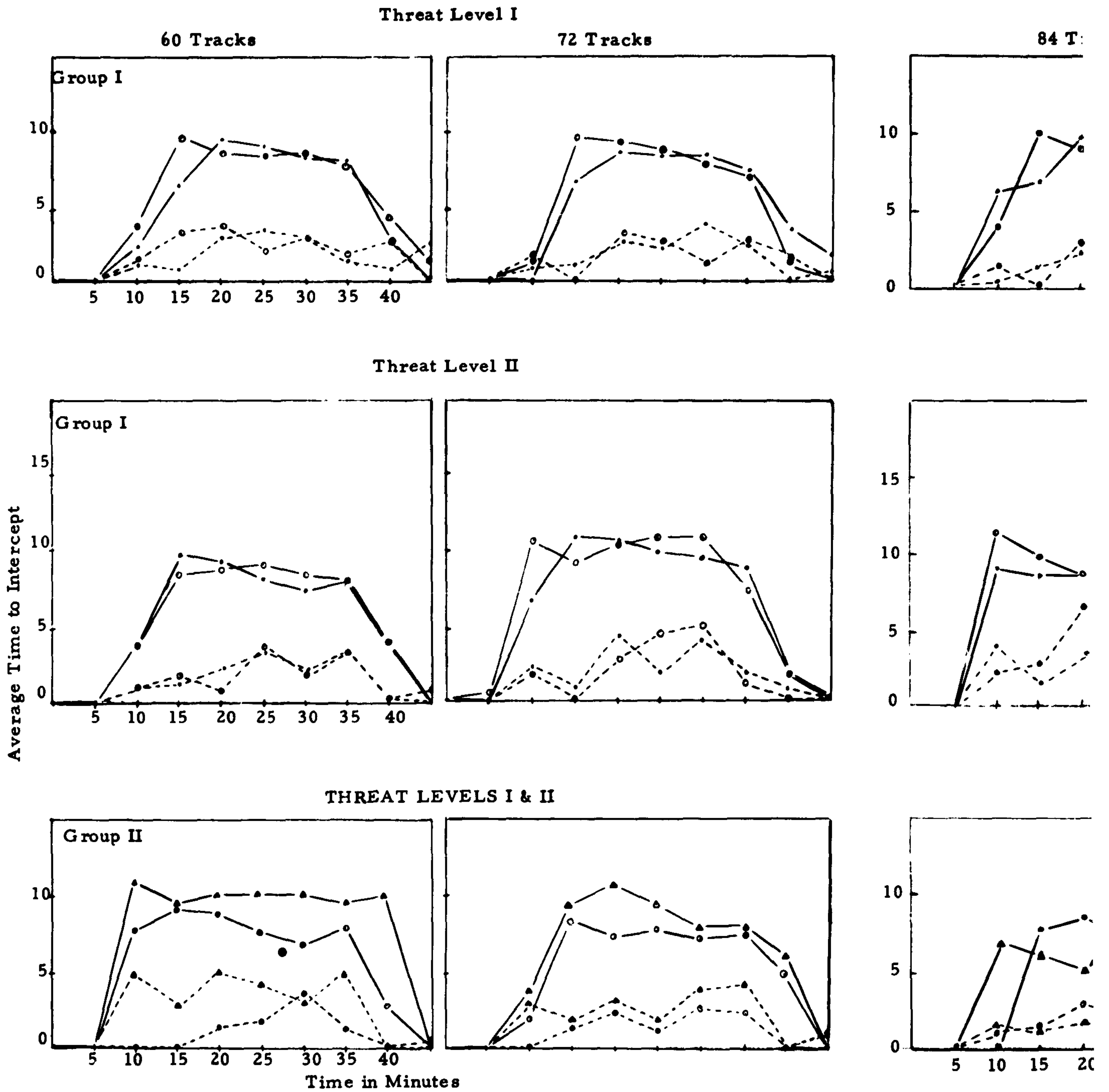
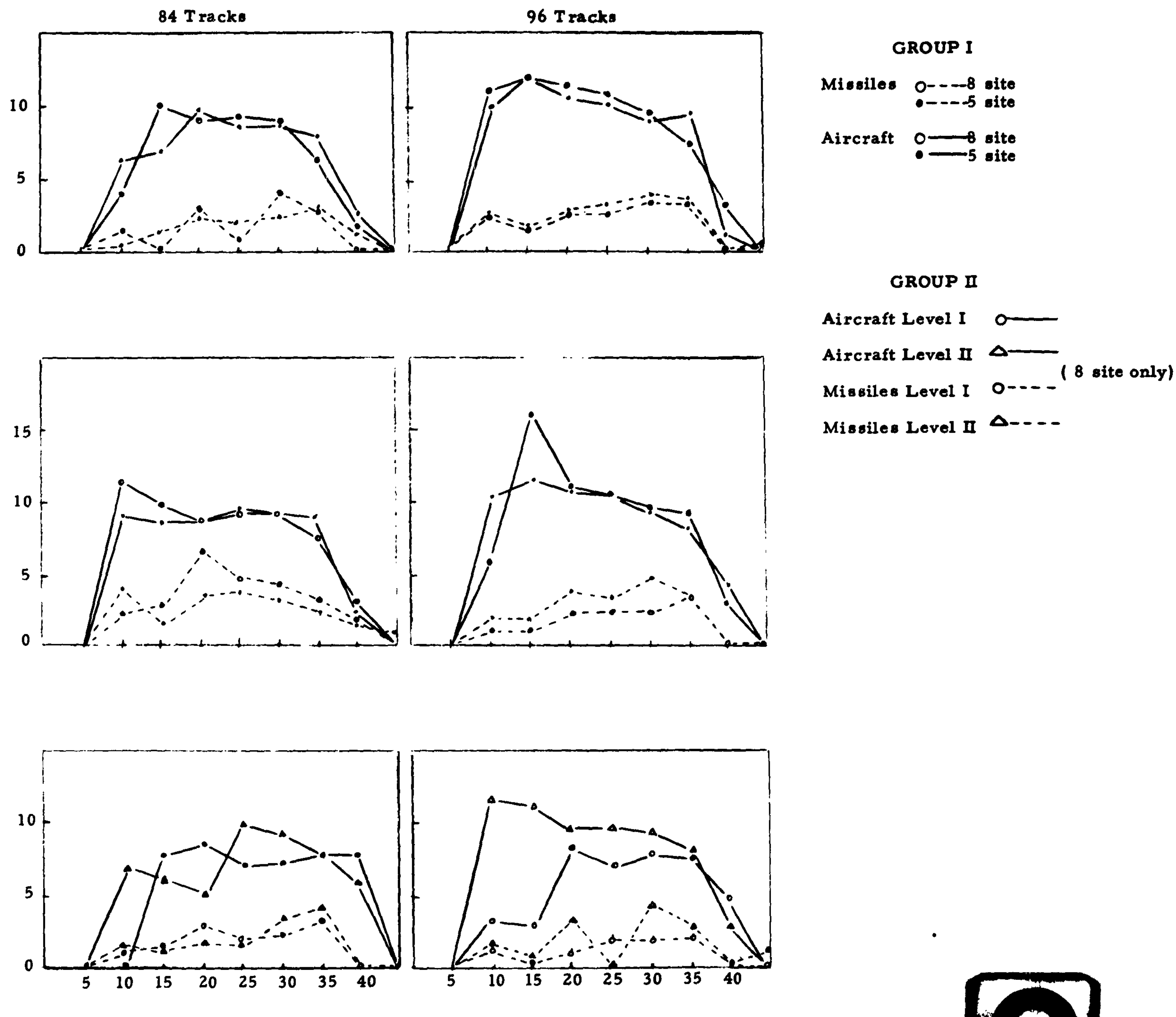


Figure 13. Average intercept times achieved for fighter and missile interceptors (Both Commander Groups).



84 Tracks
96 Tracks
0
5
10
15
5 10 15 20 25 30 35 40
GROUP I
Missiles 8 site
5 site
Aircraft 8 site
5 site
GROUP II
Aircraft Level I
Aircraft Level II
Missiles Level I
Missiles Level II
(8 site only)

Under heavy load conditions some threats should be missed (not reacted to at all) and others should be reacted to only after considerable delay. Tables la and lb, below, summarize the median delay time (average of subject medians) and gives the range of these medians for all conditions of load, threat level, site configuration, and subject group for the first action and for the first reassignment, if any, against each track.

The median response time remained about the same for all load conditions, for a given level of threat, for Group I data. The overall median delay for Group I for threat level II was, however, 20 seconds greater than it was for threat Level I. Similarly, the delay difference for Group I subjects for the first reassignment, threat level I versus threat level II, was only 3 seconds (1:27 for threat level I vs. 1:30 for threat level II). To put these delays in proper perspective, it must be pointed out that the fact that the delays shown do not increase seriously at the heaviest (96) track loads indicates a considerable increase (lower loads were presented first) in ability to select actions, since at this level over 50 per cent more tracks are available for processing than at the initial problem level (60 tracks).

Delays in acting against threat level I bomber tracks are somewhat longer (39 seconds) than the delay for all tracks processed (1:46 vs. 2:25). For threat level II bomber tracks, the difference in delay is 41 seconds (2:06 vs. 2:47). This increase in delay may be explained as partly due to the fact that usually the bombers enter the problems from the remote edge of the situation display. Thus, initially, they

TABLE 1a

Median Delay Times for Initial Assignments Against Threat by Experimental Conditions

INITIAL ACTION		Track Load 60	72	84	96	Row Mean
Group I						
Threat Level I	All	1:37	1:46	1:46	1:51	1:46
	Bomber	2:00	2:46	2:39	2:16	2:25
	Fighter-Bomber	1:43	1:15	2:05	1:55	1:55
	Fighter	1:32	1:11	1:19	1:38	1:25
Threat Level II	All	2:25	2:17	1:42	2:02	2:06
	Bomber	2:51	2:40	2:18	3:18	2:47
	Fighter-Bomber	1:24	3:10	1:44	2:35	2:18
	Fighter	1:52	1:55	1:29	1:34	1:43
Group II						
Threat Level I	All	3:11	3:45	3:56	4:31	3:51
	Bomber	3:48	10. 20	7:34	8:26	7:32
	Fighter-Bomber	3:10	1:42	5:59	3:18	3:32
	Fighter	2:01	1:35	1:44	1:49	1:47
Threat Level II	All	4:08	6:09	4:31	5:44	5:10
	Bomber	5:45	5:43	8:26	12:09	8:01
	Fighter-Bomber	6:30	13:03	3:18	5:48	7:10
	Fighter	2:59	1:59	1:49	5:58	3:11

TABLE 1b

Median Delay Times for Second Assignment Against Threat by Experimental Conditions

SECOND ACTION

		Track Load 60	72	84	96	Row Mean
Group I						
Threat Level I	All	1:10	1:10	1:43	1:44	1:27
	Bomber	1:01	1:19	1:41	1:52	1:28
	Fighter-Bomber	0:56	1:10	2:17	1:38	1:30
	Fighter	1:05	1:01	1:34	1:28	1:17
Threat Level II	All	1:19	1:24	1:18	2:05	1:30
	Bomber	1:38	1:41	1:34	2:34	1:52
	Fighter-Bomber	2:15	1:57	1:52	1:58	2:00
	Fighter	1:10	1:15	1:21	1:41	1:22
Group II						
Threat Level I	All	0:35	1:12	1:19	1:13	1:05
	Bomber	0:50	1:11	1:14	1:07	1:05
	Fighter-Bomber	0:35	1:58	0:58	1:44	1:18
	Fighter	0:41	1:06	1:00	1:12	1:00
Threat Level II	All	0:55	1:10	1:18	1:18	1:05
	Bomber	0:50	0:55	1:07	1:15	1:02
	Fighter-Bomber	1:00	1:16	1:44	1:10	1:18
	Fighter	1:00	1:13	1:12	1:12	1:09

are located far from the defended sites. Hence, the obtained delays support the observation that tracks near the sites were processed more rapidly. Median delays for second action on bomber tracks averaged 1:28 for threat level I, and 1:52 for threat level II, indicating a slight increase which may be due to the increased complexity of threat level II. The difference between the median delay for all second actions and median second action delay for bombers alone by Group I is only 3 seconds (1:27 for all second action delays vs. 1:30 for reassignment on bombers). For threat level II the difference between the median delay for all second actions and second actions on bombers is 22 seconds (1:30 for all second action delays vs. 1:52 for bomber second action delays), again in the direction of more delay on bomber tracks.

Tending to counterbalance the longer delays in acting against bombers, delays on fighters were slightly shorter for Group I when compared to the median first action delay for all tracks (1:25 vs. 1:46 for threat level I, and 1:43 vs. 2:06 for threat level II). Again considering Group I alone, on the second action there was no marked effect of threat type (delay was 1:27 for all tracks vs. a range of 1:17 to 1:30 for all classes in threat level I, and delay was 1:30 for all tracks vs. a range of 1:22 to 2:00 for all classes in threat level II).

The second group (II) delayed longer, in general, in initiating all first actions than did Group I. However, they reassigned for the second actions with a slightly shorter delay than did Group I (1:05 for Group II vs. 1:27 for Group I for threat level I, and 1:05 for

Group II vs. 1:30 for Group I for threat level II). This difference may be explained in part by the previously described tendency of Group II to concentrate primarily on the tracks adjacent to the weapon sites, as indicated when the delays for the specific threats--bombers and fighter-bombers--are considered. These subjects (Group II) were apparently preoccupied with preventing damage to their sites.

To achieve optimum solutions to these simulated battle problems, attention must be given to each track as soon after track initiation as possible. The purpose of the long range missile, in part, was to permit the commander to take potential high threats out of the problem at the earliest possible time and at greatest distances, thereby reducing not only the threat potential but also the subsequent workload.

9. Weapon posture at termination of each mission

One aspect of the commander's assigned task was to retain a capable weapon posture while sustaining minimal damage, and destroying as many threat vehicles as possible. Thus, number of weapons remaining at the end of each mission provides another indication of how well the commander processed each load level. Table 2, below, summarizes the average number of weapons remaining at the end of each mission by load, threat level, site configurations, and subject groups. In these data we can see that both subject groups were quite similar in performance. Load shows its effect in that the percentage of weapons remaining falls off as load increases. Group II retained more weapons at the highest load level, but this may be

TABLE 2

Weapon Capability Remaining at End of Missions

	Threat Level I								Threat Level II							
	60 Sites		72 Sites		84 Sites		96 Sites		60 Sites		72 Sites		84 Sites		96 Sites	
	5	8	5	8	5	8	5	8	5	8	5	8	5	8	5	8
GROUP I																
Missiles	17	17	15	15	18	16	15	11	16	16	8	4	16	13	12	7
Aircraft																
Green	9	11	12	11	14	18	18	16	10	8	11	12	9	8	16	6
Blue	17	19	17	16	11	13	18	18	9	11	14	14	15	14	20	18
Red	13	14	11	14	16	18	13	15	23	25	15	19	26	30	17	21
Total Remaining	56	61	55	56	59	65	64	60	58	60	48	49	66	65	65	52
Total Available	125		135		165		180		130		140		170		185	
Percentage Remaining	44.8	48.8	40.7	41.4	35.6	39.4	35.6	33.3	44.6	46.2	34.3	35.0	38.8	38.2	35.1	28.1
GROUP II																
	8	-	8	-	8	-	8	-	8	-	8	-	8	-	8	-
Missiles	12		11		12		16		1		8		6		14	
Aircraft																
Green	12		14		14		17		11		9		10		12	
Blue	19		19		21		26		13		11		15		17	
Red	12		11		14		17		22		14		23		24	
Total Remaining	55		55		61		76		47		42		54		67	
Total Available	125		135		165		180		130		140		170		185	
Percentage Remaining	44.0		40.7		37.0		42.2		36.2		30.0		31.8		36.2	

because those commanders were unable to make as many assignments at this level of load as were made by Group I commanders. For Group I, differences in residual weapons between threat levels and between site configurations were very small.

B. Probabilistic outcome sampling efficiency.

In real battles action outcomes are probabilistic in nature and will undoubtedly remain so, primarily due to the complexity of the conditions associated with them. To simulate this aspect of the executive function a probability distribution ranging from zero chance of success for a single action to near certainty (.999-- 3 salvos of 3 missiles in short range mode) was generated for this experiment (cf Appendix II). This distribution was used to provide a wide variety of success or failure values associated with the alternative action choices put before the commander. It is believed that the ability to assess accurately and rapidly the conditions and implications of actions, as they are conditioned by changing outcome values, will be a prime requisite of the executive decision-making role in future surveillance systems.

In this study the probability value associated with each action outcome is a more sensitive indication of the value or magnitude of the action selected than is the fact that the action consisted of, say, assigning three aircraft instead of one to a track. Under certain circumstances, for example, three Red aircraft can have a probability of successful outcome as low as .5 or as high as .8. Figure 14, below, summarizes the selection of outcome probabilities by load, threat

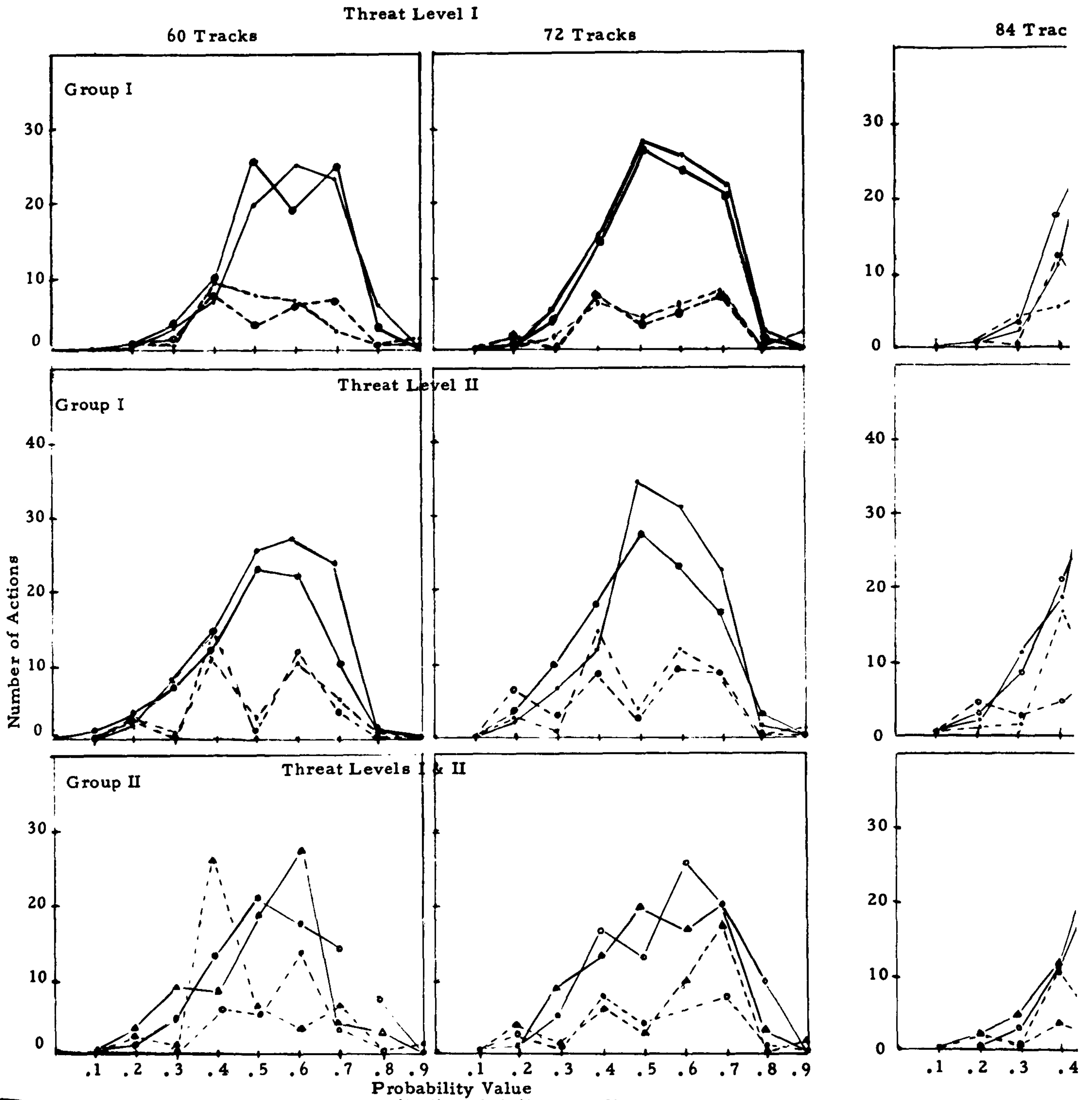
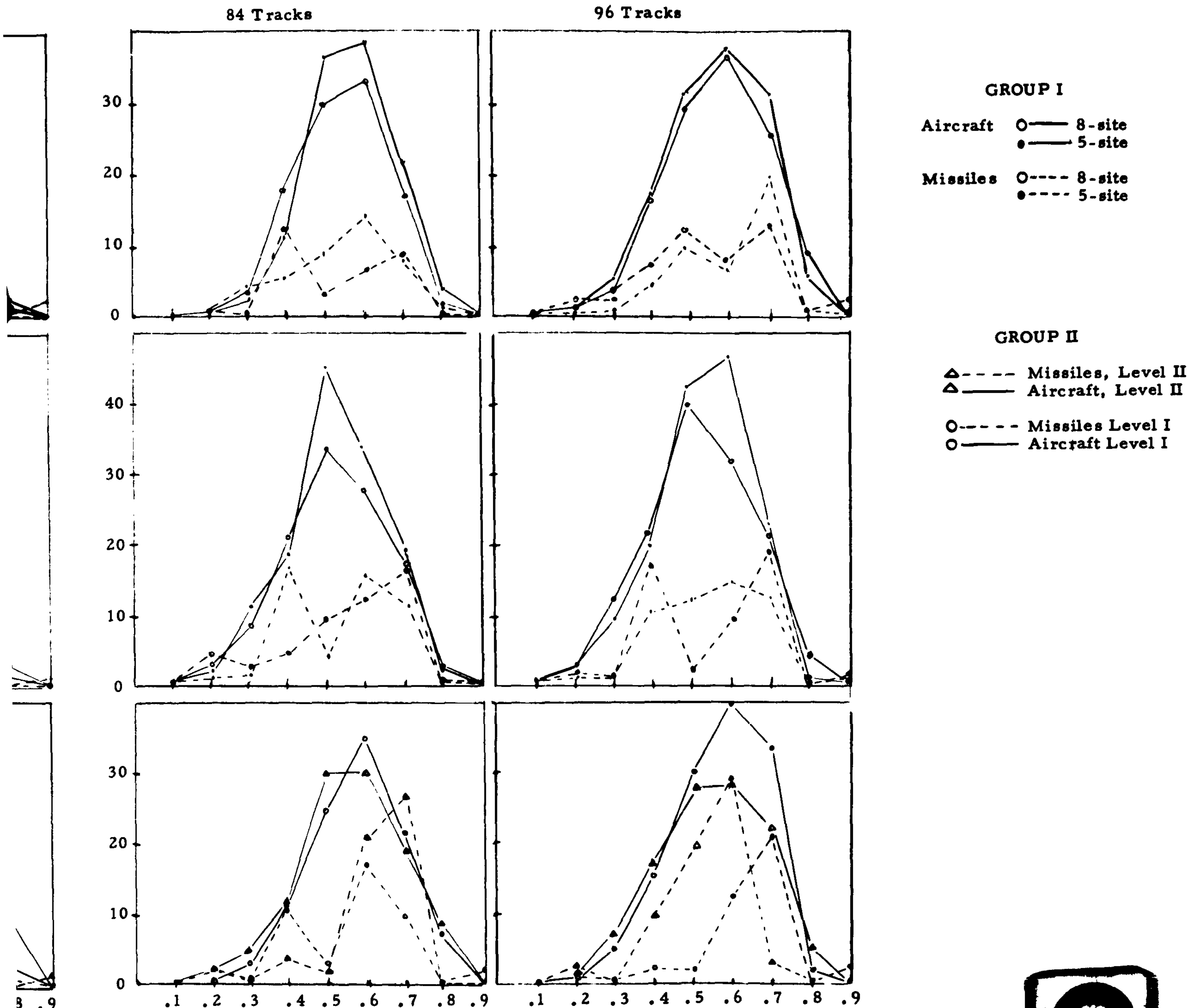


Figure 14. Action outcome (kill) probability sampling distributions.


84 Tracks
96 Tracks
0
10
20
30
40
.1 .2 .3 .4 .5 .6 .7 .8 .9
GROUP I
Aircraft 8-site
5-site
Missiles 8-site
5-site
GROUP II
Missiles, Level II
Aircraft, Level II
Missiles Level I
Aircraft Level I

level, site configurations, weapon class (missile or fighter-interceptor) and commander groups. Each point represents the number of times that each probability value was sampled. Derivation of the population universe is a nearly impossible task considering the number or weapons available and their possible combinations. Missiles alone, for example, may be drawn one, two, or three at a time, and in the short range mode, even up to nine may be assigned to a single action. With 60 items in the inventory, however, only a few such draws could be made before the inventory was exhausted. One single function descriptive of missile kill probability sampling, i.e., showing the mean potency of the commander's action choices, could be generated, but it would have to be based on average values from many combinations of possible missile sampling rates, polled across load conditions, subject groups, etc.

Figure 14 presents several aspects of how the commanders sampled the probability values. The modal point for sampling probabilities, i.e., the most commonly selected potency of weapon assignment, for aircraft ranges from .5 to .6 (for both levels of threat, both groups) and shows no decrease with increasing load. Such a decrease might have been expected on the basis that increased load might produce increased delay in assigning, increased rate of inappropriate assignments, and other decrements in action selection performance. Any such decreases in decision effectiveness would, of course, be reflected in lower kill probabilities, since the probability is based on consideration of the several dimensions of decision. Except for Group

I at the highest load and second level of threat, no changes are apparent; there, the eight-site sampling for aircraft remains at .5, while the five-site sampling has increased to .6. Also to be noted is the fact that slightly more items are selected at the middle values in the five-site mode (Group I).

Probability sampling for the missiles shows a tendency toward bimodal distribution. This trend begins to drop out at the highest load for Group I and quite definitely stops for Group II. Group II commanders also tended to select more of the higher probability missile combinations.

Group I shows essentially the same sampling for the five vs. the eight-site configurations, except that, in general, more actions of each value were selected for threat level II, the problems with a larger actual number of threatening hostile tracks. For Group II throughout there is a tendency to employ proportionately more aircraft than missiles for threat level I and to reverse this preference for threat level II.

C. Damage Assessment

At first consideration it would seem that damage sustained would provide a good indication of how well a surveillance and control system had functioned. However, prevention of damage to his weapon sites is but one aspect of the overall task the commander was given. Also, sustaining damage does not indicate necessarily that the decision-making complex functioned inadequately. Rather, damage may in many cases be due to the binary nature of the outcome of the particular

actions chosen. For any one sample set of actions, high probability outcome choices may, due to chance, show a relatively higher or lower number of kills. This research is more concerned with whether the commander adjusted to the result of the damage assessment and still functioned effectively. In some cases, the commander may have had to accept a lesser damage to prevent a greater damage; for example, to accept fighter penetrations while reserving weapons to kill bombers and other high priority threats.

1. Total damage assessed

The average total damage assessed for all experimental conditions is indicated, below, in Figure 15. The upper set of graphs indicates total damage incurred by Group I at different loads. The circle and solid line entry indicates threat level I and eight-site damage; the circle and dotted line indicate threat level I and five-site damage. Within this portion of the figure, the upper solid line and dot indicate threat level II and eight-site damage, while the dotted line and the dot indicates five-site damage. The lower portion of the figure indicates the damage incurred by Group II. The dotted line indicates the damage for threat level I, and the solid line threat level II. Inspection of these figures shows that Group II received somewhat more damage across threat levels, and notably more damage at load 96 for threat level II. These commanders received less practice at each load level and thus had less chance to adjust to each level of load and develop a strategy to cope with the load to the same extent that Group I did. Hence, more damage under conditions of maximum

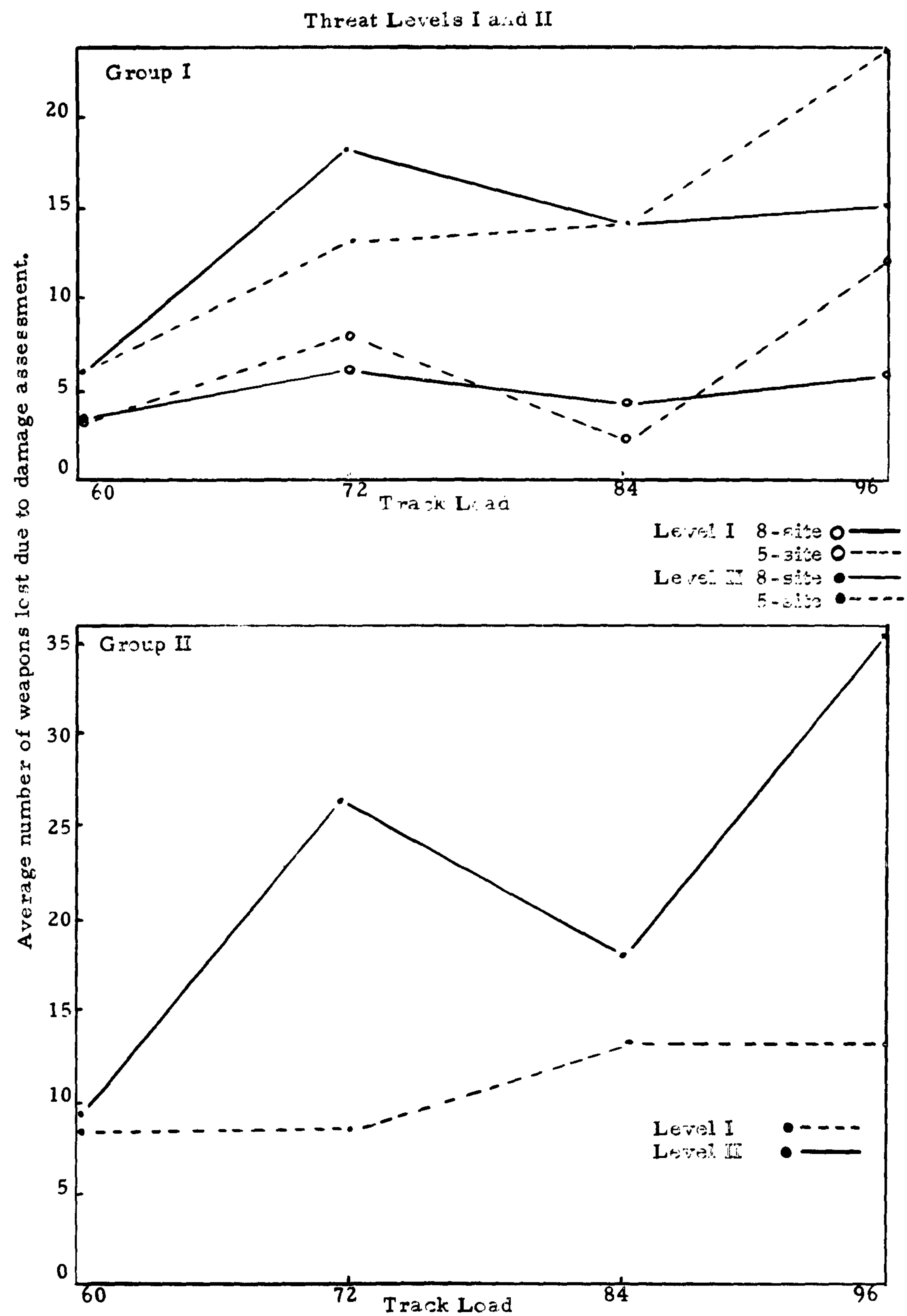


Figure 15. Total damage assessed.

problem difficulty might have been expected, and in fact it was found.

The commanders in Group I were cautioned that the five-site problems might be more critical for damage, due to the fact that the same total weapon inventory was stored in fewer locations. Hence, a hit would have the potential of destroying a larger share of the weapons. Figure 16 summarizes the damage received for the sites that were common to both the five-site and the eight-site configurations. The forward airfield (site number one) is represented by the uppermost set of graphs. This site received the greater amount of total damage, particularly when it appeared in the five-site mode, for threat level II. The next lower set of graphs describes the damage received by airfield three. Here, it may be seen that both threat levels caused almost no damage except for the highest load level in the five-site configuration. The set of graphs next to the bottom set summarizes damage to airfield four. For this field threat level I produced about the same damage for all loads and for both site configurations. Threat level II, which included tracks with a great total capacity to damage, caused more damage in general. The eight-site configuration showed more damage forthe first three loads, but this graph crosses below the function representing the five-site rate at the highest load level. The lowest set of graphs stands for missile site B. It is apparent, here, that very few penetrations were permitted in this weapon area although several were possible. In the five-site configuration, damage was caused only at the highest load level and threat level II.

The previous figure indicates that, as a rule, damage was

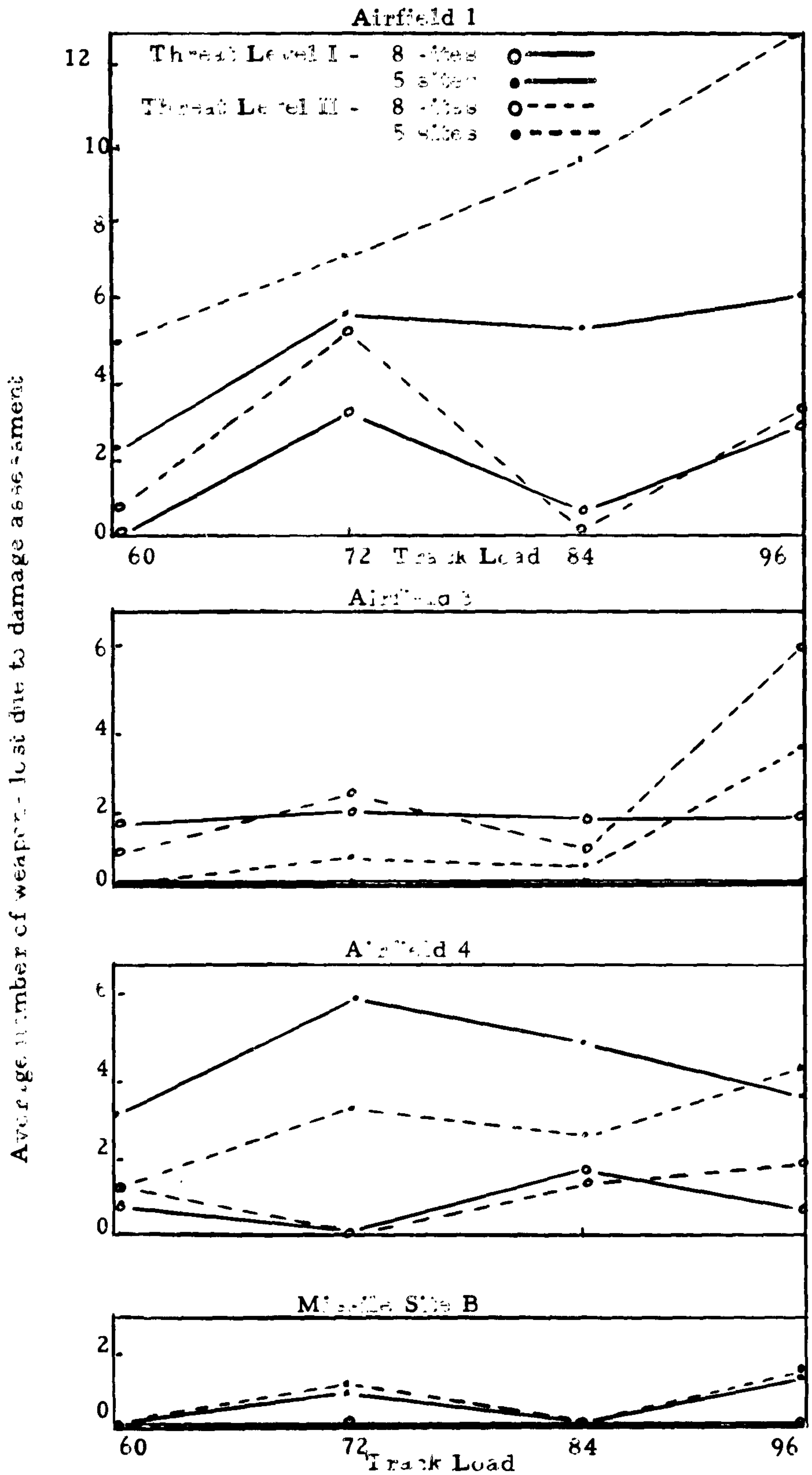


Figure 16. Damage assessment for weapon sites common to the 5 and 8-site configuration.

confined to the forward area sites. Of additional interest is the problem time when damage began to occur. On the basis of the problem program one bomber penetration could have occurred as early as five-minutes from problem onset. Figure 17 summarizes the damage assessment as a function of problem time.

The left-hand set of graphs summarizes the damage for Group I. Load is indicated downward from the top of the page. In general, the differences between site configurations are negligible until the terminal portion of load 96. The early damage indicated for the eight-site, threat level II problem for loads of 72 and 84 was due to the early bomber penetrations mentioned above. This threatening target was usually assigned with the appropriate matching fighter, but this fighter could not complete the intercept before bomb drop time. The graph for this condition (eight-site, threat level II) for load 96 shows that the commanders were able to eliminate this kind of threat if they hit on the plan of an appropriate use of missiles.

Turning to the performance of Group II (right hand page), we can see that the less experienced commanders were unable to eliminate this particular threat (early bomber). The reduced scale of the ordinate is intended to permit a relative comparison between the two groups. As in previous summaries it may be seen that threat level II caused, in general, more damage for this group. Again, as with Group I, the Group II executives were able to prevent most of the damage for the first twenty-five minutes of the problems. It is to be recalled that the load within each problem also peaked shortly after this time, and the effects of this increase in the internal load are apparent in the damage

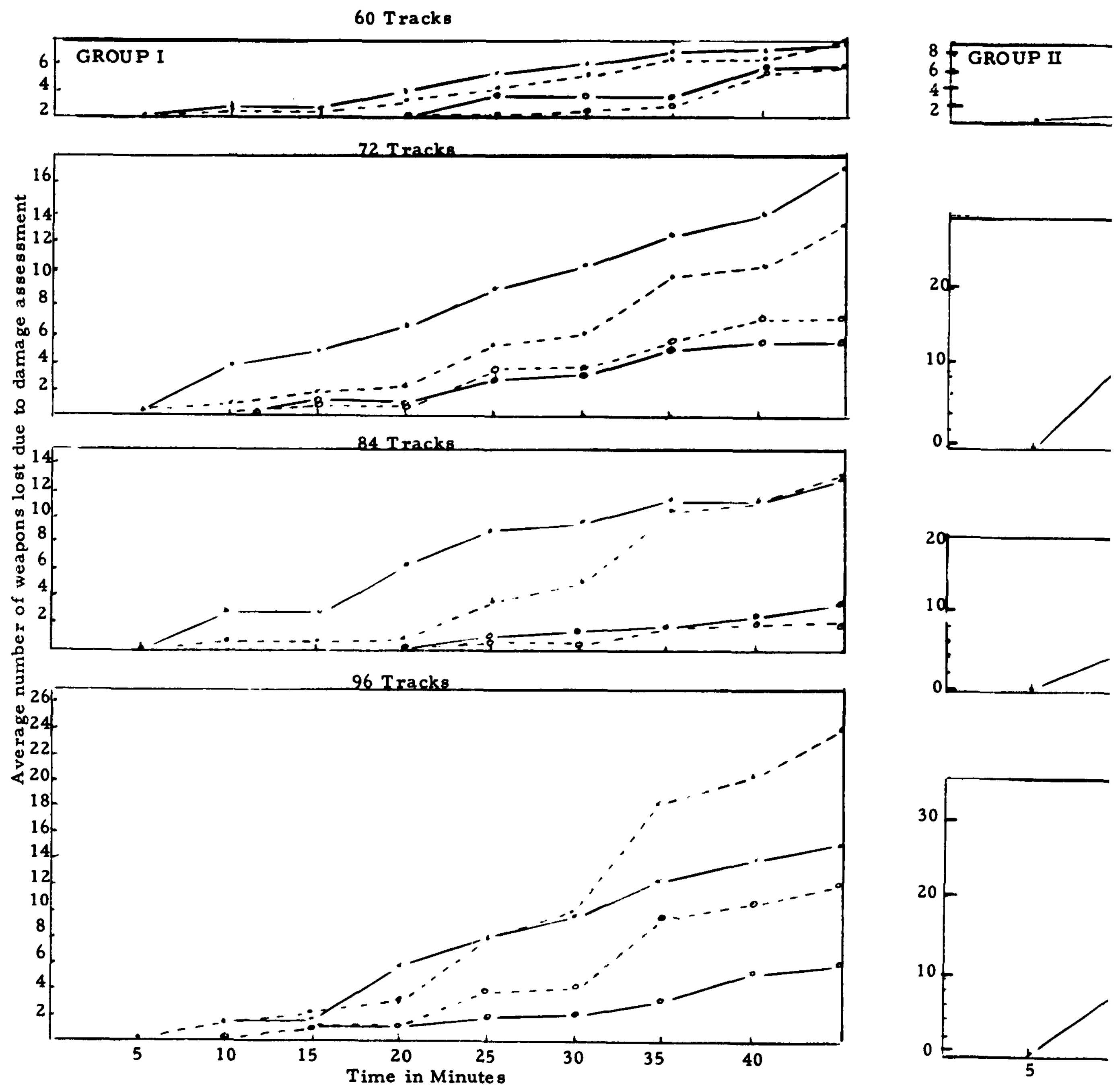
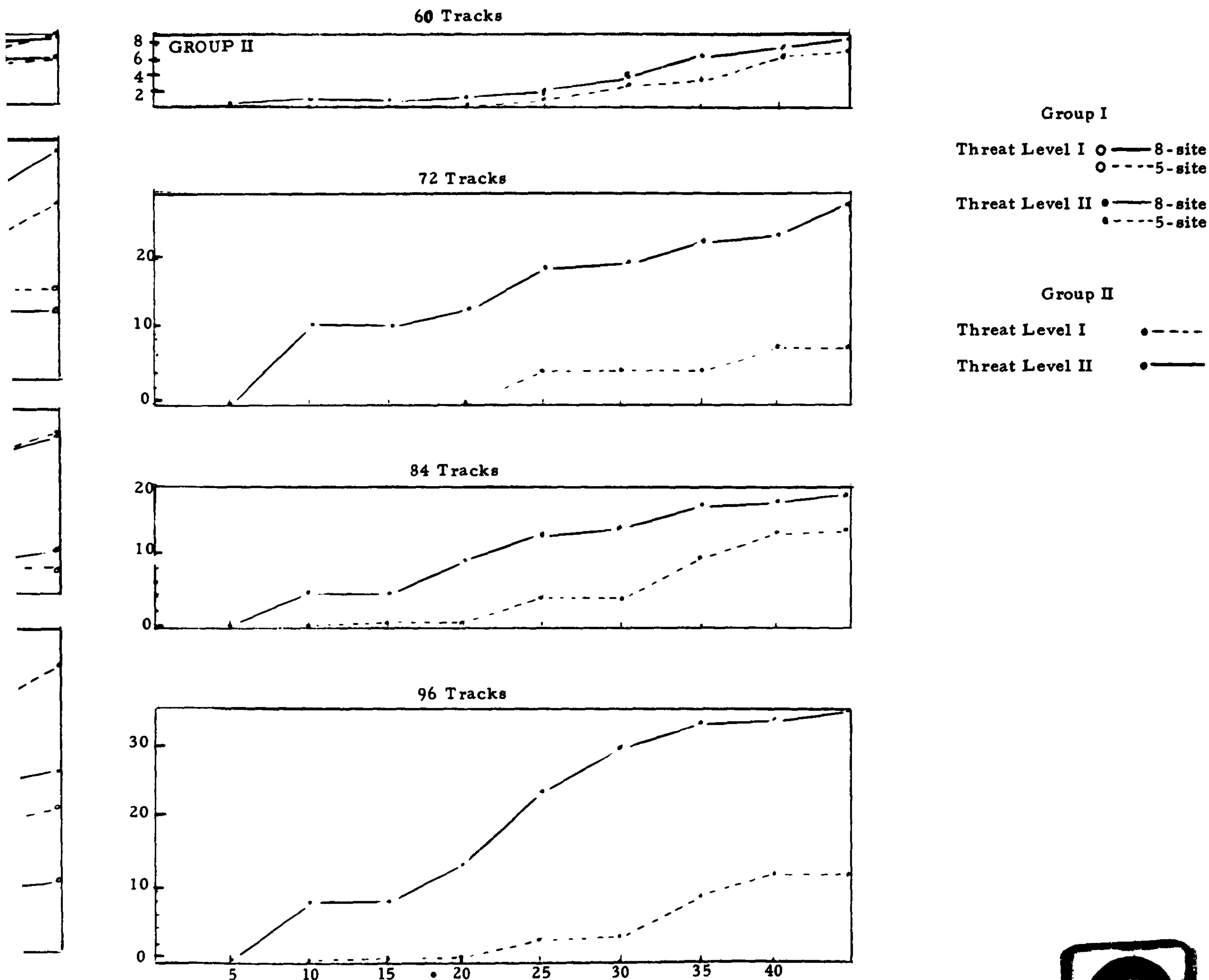


Figure 17. Damage assessment as a function of time in problem.


60 Tracks
GROUP II
8
6
4
2
72 Tracks
20
10
0
84 Tracks
20
10
0
96 Tracks
30
20
10
0
5
10
15
20
25
30
35
40
Group I
Threat Level I
8-site
5-site
Threat Level II
8-site
5-site
Group II
Threat Level I
Threat Level II

sustained. (cf. Appendix I for potential penetrations cumulated over time).

It is to be noted that on only one occasion did a site (Red airfield two) have to be closed down due to two successful bomber penetrations, although at several sites as many as four or five bomber penetrations were possible. When this over-kill potential is considered, it is apparent that a creditable performance was turned in by both commander groups. A consideration of the analytic solutions (cf Table 8) also indicates this fact. Only rarely does an analytic solution indicate no damage whatsoever.

D. Data Processing Efficiency.

1. Hostile tracks not processed

This section is intended to show how adequately various aspects of the presented data were considered by the experimental commanders. It has been shown previously (Figure 10) that the commanders could not discriminate the "real" threats in the time they had to act, with the kind of information that was presented. Also, there was no indication that, as load increased and as they received additional exposures to the program, they were able to single out certain aspects of the threat for special treatment or consideration. In fact, all tracks were reacted to as real threats, and in some cases as with actions against the fighter inputs, the actions selected were greater than necessary against the particular threat class.

Table 3, below, summarizes the hostile tracks not processed under different conditions of load and damage potential. It can be seen that some potentially damaging tracks are missed by both groups

TABLE 3

Total Number of Hostile Tracks not Processed by Both Experimental Groups

GROUP I

N=6

		60 Sites				72 Sites				84 Sites				96 Sites			
		5		8		5		8		5		8		5		8	
		D*	ND**	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND
Threat Level I	B	-	2	1	1	1	6	2	4	-	3	-	7	1	2	-	2
	FB	-	2	-	1	2	7	-	1	-	2	-	2	-	1	-	2
	F	1	3	1	4	-	6	2	4	-	5	-	3	1	3	-	3
	O	-	-	-	1	-	3	-	3	-	-	-	-	-	1	-	1
		1	7	2	7	3	22	4	12	0	10	0	12	2	7	0	8
Threat Level II	B	-	4	2	1	3	3	1	3	1	3	1	1	2	3	4	6
	FB	-	-	-	1	-	2	-	3	-	3	-	3	-	1	-	1
	F	4	2	-	3	4	2	8	5	1	1	2	4	2	3	3	3
	O	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
		4	6	2	5	7	8	9	11	2	7	3	8	4	7	7	10

GROUP II

Hostile Tracks Not Processed

		60		72		84		96	
		D	ND	D	ND	D	ND	D	ND
Threat Level I	B	1	0	3	5	0	1	0	1
	FB	0	0	0	1	0	1	0	1
	F	1	0	0	4	0	1	0	1
		2	0	3	10	0	3	0	3
Threat Level II	B	0	1	0	1	1	0	1	2
	FB	0	0	0	0	0	1	0	1
	F	1	0	0	0	1	3	2	1
		1	1	0	1	2	4	3	4

*Damage Potential

**Non-damage Potential

throughout the experiment. Although with practice both groups showed considerable improvement in processing the increasing load, Group II, with less experience, was still considerably below the main group in performance as judged by this index. The success of Group II in coping with the real threat is only an apparent advantage (cf Figure 13), since this success was achieved by delaying the response to a track until the intent was quite obvious. This increased delay was not purposeful--these commanders just could not process the increasing load at any faster rate. It was shown previously, that their reaction times to scramble against the bomber and fighter-bomber inputs were somewhat longer than the delay times for Group I. They were apparently so occupied in processing tracks that were near the sites they could not attend to the tracks that initiated in remote areas of the situation display. Such remote tracks should, under more favorable load conditions, have been killed before their threat became acute.

The increase in missed tracks at the 72 track load appears to be a practice effect, especially for Group I, as the higher loads show fewer tracks not processed. The total not processed for Group II for threat level II and 96 tracks is 2 per cent of the total tracks, the total for Group I for threat level II and 96 tracks is 1 per cent of the tracks not processed. The commander had the option of accepting a possible penetration by a fighter, which could inflict only a single weapon penalty. Yet, from the very low numbers of unprocessed tracks, it appears that they did not employ this option, but rather attempted to continue to maximize kills throughout the entire course of the experiment.

2. Inappropriate application of weapon criteria

To make effective decisions, i.e., to select actions having high probabilities of kill, the commander had to apply correctly the matching criteria to the incoming threat tracks. This aspect of his task consisted mainly of selecting a weapon that could match or outperform the speed and altitude of the incoming track. Also, a scramble site had to be selected with a view toward achieving a short intercept time and an extra margin that would allow the intercept even if the track should turn away to make the action into a tail chase.

(a) Weapon matching with target tracks.

Since the surveillance data were presented as 100 per cent reliable, and since the weapon inventory was tailored to the problem load, mis-matching by under matching could be due only to error on the part of the commander. When an undermatch occurred, it might have been due to a momentary confusion of the commander such that he mis-appraised the characteristics of the threat track. Of course, the chance cannot be ruled out that when faced with a depleted weapon inventory, a commander might permit some faint hope, e.g., a change in threat track speed, altitude or a heading might make a match out of an apparent mis-match--to influence him to order into action a weapon of inadequate capability. The referee team did not believe, however, that this "hope" hypothesis accounted for any substantial number of actions.

Table 4 summarizes mis-match performance. We can see that mis-matching reached a peak at the third load level (84 tracks). After that load, the commander's performance began to improve

TABLE 4

Distribution of Inappropriately Assigned Weapons by Threat Category

			TRACKS 60 THREAT			72 THREAT			84 THREAT			96 THREAT		
			B	FB	F	B	FB	F	B	FB	F	B	FB	F
THREAT LEVEL I	Group I	5 Sites	1	0	4/5	2	2	4/8	10	0	6/16	4	2	6/12
		8 sites	1	0	9/10	2	5	9/16	4	2	13/19	9	0	8/17
	Group II	8 sites	1	0	2/3	2	2	2/9	3	2	5/10	2	0	1/3
THREAT LEVEL II	Group I	5 sites	0	1	3/4	5	2	9/16	0	6	13/19	3	1	1/5
		8 sites	2	0	8/10	7	5	4/16	7	4	8/19	3	1	1/13
	Group II	8 sites	0	0	1/1	2	0	4/6	1	0	2/3	4	0	6/10

considerably. The eight-site problem appears to have been more difficult but performance improved here also. The total of 29 under-matches out of 1152 possible tracks at load 96 and threat level I for Group I indicates a mis-match error of approximately two and one-half per cent.

The second group of commanders generated fewer actions, but their mis-match rate also was a little over two per cent. Out of 7116 foe and unknown tracks (cf Appendix II) presented to Group I, they mis-assigned on 60 bombers, 31 fighter-bombers, and 114 fighters, for a total of 2.9 per cent error. Group II mis-assigned on 15 bombers, 4 fighter-bombers, and 26 fighters of a total of 1229 foes and unknowns for a total of 2.5 per cent error.

(b) Weapon choices resulting in tail chases.

At the moment that the typical action choice was made, the commander could not judge with absolute certainty that the particular intercept would not result in a tail chase. The commanders in this study were not shown weapon track data; they were told that the weapons were monitored by a transponder reporting-in to the machine that handled the intercept computations, and they were told further that inappropriate actions would be signaled to the commander via his technician. The reason for this system was that to generate and make available track data on the approximately 4,000 intercepts scored for this study would have required a very large storage capability and a large facility to program real-time feedback. It is doubtful whether weapon track data would have aided the commander in locating inappropriate intercepts in advance of the signal fed-back to him, due to the

heavy track loads involved. At any rate no commander decommitted in advance of any inappropriate action signals. In fact, this is apparently one avenue taken by the executive to reduce the work load--to wait for such information from the system.

If a commander waited long enough, a tail chase situation would become obvious; with a tail chase established, to kill would require a missile or a manned interceptor with a large speed advantage. The commanders appear to have performed relatively well (see Table 5 below.) The table presents absolute numbers, ranging from zero tail chases for the 60 and 84 track loads (with Group I commanders in the five-site configuration) to a high of twenty-three tail chases for the 96 track load (with the same commanders in the eight-site configuration). Interpretation of these absolute numbers should take into account the larger total number of intercepts at higher problem loads and the much larger number of problem runs with Group I subjects. When such differences in all entries are considered, there is no consistent effect of track load upon rate of tail chase generation. Second, it is apparent that there were, overall, very few tail chases. All conditions pooled yields about two per cent tail chases.

(c) Distribution of action choices resulting in out-of-range intercepts.

A more serious error than tail chase generation is commitment of a weapon to an impossible intercept. The discrimination made at the situation display to evaluate the possibility of achieving intercept before the target track goes out-of-range is quite similar to the judgment of tail chase probability at the time of assignment. When

TABLE 5

Distribution of Weapon Assignments Ending in Indeterminate Tail Chases

			TRACKS											
			60 THREAT			72 THREAT			84 THREAT			96 THREAT		
			B	FB	F	B	FB	F	B	FB	F	B	FB	F
THREAT LEVEL I	Group I	5 Sites	3	1	8/12	0	0	4/4	4	3	12/19	4	2	11/17
		8 sites	5	3	3/11	0	0	8/8	6	2	3/11	12	5	6/23
	Group II	8 sites	3	1	0/4	0	1	1/2	4	2	5/11	5	2	3/10
THREAT LEVEL II	Group I	5 sites	0	0	0/0	0	0	0/	0	0	0/0	1	0	2/3
		8 sites	2	0	6/8	4	0	8/12	6	2	5/13	3	1	4/8
	Group II	8 sites	0	0	0/0	2	0	3/5	1	0	1/2	2	0	3/5

an out-of-range scramble had been ordered the commander had the opportunity to consider the track for 10 minutes. After that period the system signaled that the outcome would be negative in ten more minutes. As stated previously for tail chase assignments, the commander relied heavily on this feed-back of mission outcome.

The frequency distribution of actions going out-of-range is indicated in Table 6, below. Reference to that table shows that Group I selected more inappropriate actions in this regard for the eight-site configuration, and also selected more, in general, for threat level I. Group II showed no marked difference by threat level, and neither group showed consistent load effects. The total error for Group I for selection of out-of-range intercepts was a little over one per cent and for Group II it was about three per cent.

3. Estimate of hostile threat

The present study was concerned primarily with action selection performance, and for that reason little emphasis was placed upon recording direct estimates of threat. These estimates can be derived indirectly from the data by considering the kind and amount of each action employed against each input threat class. These actions were not determined by threat evaluation alone, but varied as a function of the inventory available. Hence, they do not indicate accurately how great the commander considered the various threats to be. To get around this source of inaccuracy, the commander was required to state an assignment priority, numbered from one to four, at the time of action selection. In the case of the missile actions, this priority number gave the commander the opportunity to decommit or downgrade

TABLE 6

Distribution of Intercepts Terminating Out of Range

			TRACKS											
			60 THREAT			72 THREAT			84 THREAT			96 THREAT		
			B	FB	F	B	FB	F	B	FB	F	B	FB	F
THREAT LEVEL I	Group I	5 Sites	1	5	2/8	3	1	0/4	0	8	4/12	4	6	4/14
		8 Sites	1	4	6/11	5	4	3/12	4	6	7/17	6	5	9/20
	Group II	8 sites	0	0	2/2	0	0	2/2	0	4	3/7	0	4	2/6
THREAT LEVEL II	Group I	5 sites	0	0	0/0	0	0	0/0	2	0	0/2	1	0	0/1
		8 sites	4	3	7/14	3	2	2/7	11	2	3/16	3	4	4/11
	Group II	8 sites	1	0	0/1	1	0	0/1	5	0	3/8	5	0	0/5

low-priority assignments, and employ the weapons on higher priority threats without entirely passing over a lesser threat. In the commanders training and instructions, threats were ordered as follows: a bomber was considered a priority one target; a fighter-bomber, priority two; a fighter, priority three; and other threat categories (cargos, troop carriers, and reconnaissance), priority four. A bomber departing from the situation, but which the commander still desired to kill so as to deny hostile capability, could be indicated as priority two or even three. A fighter-bomber about to penetrate a site should be called a priority one target. The frequency with which each of the four priorities actually was assigned in the study is presented below, in Table 7.

Reference to Table 6 shows that the primary order was followed very closely except in the case of the fighter inputs; these were grossly overrated. The bombers were generally called "priority one", with Group I showing a tendency to report many of them as "priority two." Fighter-bombers were generally called "priority two" but both groups showed an increasing tendency across load (with two exceptions) to call some fighter-bombers "priority three." The fighers were labeled "priority three" for the most part, but both groups labeled some of this threat class "priority two" or even "priority one". This would appear to support previous statements that fighters were acted on somewhat out of context. Neither group discriminated "real" from "apparent" threats in their priority assignments.

4. Post-mission debriefing critique

Immediately after each experimental run the commander was debriefed on the following items: (a) Commander's assessment

TABLE 7

Distribution of Average Target Priority by Load and Commander Group
(Data pooled across sites and threat level)

LOAD

Threat Type		60 Gp.I	60 Gp.II	72 Gp.I	72 Gp.II	84 Gp.I	84 Gp.II	96 Gp.I	96 Gp.II
B	1	13.8	12.8	20.1	15.3	24.4	16.6	27.6	18.8
	2	3.3	1.8	4.0	1.6	4.3	0.2	4.1	0.6
	3	1.0	0.3	1.5	0.8	1.8	1.1	2.1	1.5
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
FB	1	1.2	0.0	2.1	1.6	3.3	8.6	4.4	0.9
	2	12.2	14.3	15.0	12.2	17.5	4.3	20.0	14.9
	3	2.0	0.2	2.1	0.3	1.1	0.0	1.3	0.5
	4	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0
F	1	2.6	0.5	2.5	1.3	4.0	2.5	3.4	1.2
	2	5.3	11.8	5.3	7.6	7.2	8.5	7.9	5.2
	3	20.5	9.6	20.4	13.9	26.6	22.5	29.4	26.6
	4	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
O	1	0.0	0.0	0.4	0.4	0.1	0.5	0.8	0.9
	2	0.1	0.1	0.6	0.5	0.4	0.2	0.5	0.7
	3	0.1	0.4	0.5	0.2	0.2	0.3	0.6	0.2
	4	0.5	0.0	0.5	0.0	0.3	0.0	0.4	0.2

of his performance in terms of success in coping with the problem, (b) Adequacy of the weapon inventory for each problem, (c) Adequacy of the pre-mission intelligence briefing, and (d) Commander's modification of action strategy for the problem.

The results of the analysis of debriefing data are summarized in Table 8, below. For item (a), the commanders were asked to rank their performance on a four-point scale ranging from believing that they were ahead of the problem (in terms of coping with it) to not being able to rate their performance. In general, it appears that the commanders developed a reasonably accurate assessment of their performance. It is to be noted that at the 60 track load level, only 8.3 per cent believed that they were ahead of the problem. This estimate rose to 29.2 per cent at load 72. The fact that half the commanders thought that they were at least abreast of this problem level is somewhat at variance with data reflecting performance in avoiding damage, since damage was disproportionately high at this level. However, other measures indicate that the performance was about the same as on other problems. For the remaining two load levels, 12.5 per cent of the commanders reported that they were ahead of the problem. The commanders that believed that they were keeping up with the load increased from 37.6 per cent to 62.5 per cent and remained there for the highest load. Commanders who reported that early in the series of problems they got behind tended to change their responses with increased experience (20.8 per cent for load 60 to zero per cent for loads 84 and 96). Finally, a large residual did not commit themselves (33.3 per cent for load 60 decreasing to 25 per cent for load 96).

TABLE 8

Commander Response to Debriefing Questions (in Per Cent)
(For Group I - pooled for threat level and intra-configuration)

QUESTIONS	LOAD 60	72	84	96	Average
1. Commanders Performance					
(a) Ahead	8.3	29.2	12.5	12.5	15.6
(b) Keeping up	37.6	45.8	62.5	62.5	52.1
(c) Behind	20.8	8.3	0.0	0.0	7.3
(d) No evaluation	33.3	16.7	25.0	25.0	25.0
2. Weapon Inventory					
(a) Adequate	50.0	66.6	70.8	70.8	64.5
(b) Inadequate	16.7	16.7	4.2	4.2	10.5
(c) No evaluation	33.3	16.7	25.0	25.0	25.0
3. Intelligence					
(a) Good	8.3	20.8	45.8	20.8	23.9
(b) Adequate	50.0	54.2	29.2	50.0	45.9
(c) Not reliable	8.3	8.3	0.0	4.2	5.2
(d) No evaluation	33.3	16.7	25.0	25.0	25.0
4. Strategy Change					
(a) Consistent with training	37.5	50.0	75.0	70.8	58.3
(b) Changed	29.2	33.3	0.0	4.2	16.7
(c) No evaluation	33.3	16.7	25.0	25.0	25.0

When the commanders were asked to evaluate the weapon inventory, reports that it had been adequate increased from 50 per cent for load 60 to 70.8 per cent for load 96. This increase may be taken as an indication that the commanders learned to utilize the weapons more effectively, since inventory stood in a constant ratio to load. Initially, a few commanders considered the weapon inventory inadequate (16.7 per cent), but this response dropped toward zero (4.2 per cent) at load 96. Also expressed initially was the feeling that more weapons in certain categories would have been desirable. This response tended to drop out as the commanders progressed through the increasing track loads.

"Intelligence" data were presented to provide the commanders with information on the general level of threat to be expected in each problem. Also, they were instructed to consider the usage of each weapon class with respect to this intelligence data. It was pointed out to the commanders that threat target expectancies varied greatly from problem to problem.

A large proportion of the commanders rated the intelligence data as "good" or "adequate" (58 per cent for load 60 to 75.0 per cent for load 96). A small proportion of the commanders (8.3 per cent for load 60 to 4.2 per cent for load 96) considered the intelligence data as unreliable. With experience a decreasing proportion of the commanders indicated no evaluation (33.3 per cent for load 60 to 16.5 per cent for load 96).

The final debriefing question was concerned with the commanders' estimation of their own consistency in approach (strategy) to the

solution of the problems. Part of the overall task was to develop a plan of solution for the problems. The commanders reported that during the training runs they tried to solve the problems primarily by utilizing the aircraft interceptors, while saving the missiles for back-up. It is to be noted, here, that while these commanders all had had a great deal of aircraft control experience, none of them had observed the control of missile interceptors. At load 60 about one-third (37.5 per cent) stated that the strategy had been to employ aircraft first, and use missiles for back-up. Roughly another third reported changing strategy on the 60 load problem, and the remaining third of the group reported no evaluation of approach. At load 96 over two-thirds (70.8 per cent) reported consistency with the approach reported for training (the basic use of aircraft with missile back-up), and about one fourth (24 per cent) reported no evaluation. Previous measures had indicated an increasing use of missiles, earlier in each problem, to cope with the increasing load.

5. Post-mission summary data feed-back on performance

At the end of each debriefing session each commander was given his performance on the just completed mission in terms of the number of kills achieved by interceptor class (missiles or aircraft), the number of penetrations sustained, and the cost in terms of weapons used per kill. This information was provided to enable the commander to validate his action approach (strategy) by assessing the overall effect of action changes which he might have introduced during the mission.

E. Analytic solutions to sample problems.

An estimate of what would be "good" solutions to sample problems was desired to provide a standard by which to judge the performance of the commanders as tactical decision-makers. These analytic solutions were not derived within a game-theoretic framework. Rather, it was felt that if little or no damage was incurred, kills were near 100 per cent, and some substantial part of the weapon inventory remained to counter other threats, adequate defense could be made of the analytic solution as "good" for the present purposes. The solutions were of a logic or problem-solving type in that specific, related rules had to be observed during derivation of each solution. These solutions would be expected to be somewhat above the actual performance of the commanders, since the latter performed in a time-constrained, dynamic situation, whereas the "analytic" or "machine solutions" were derived by strict rules and at leisure.

Three levels of solution were derived: (1) idealized "human" solutions based on two rates of assigning actions, (2) idealized "machine" solutions where delay in assigning action was zero, and (3) random "machine" solutions where action delay was zero (as in (2), but action selections were drawn at random. These three solutions were derived for two levels of load (60 and 96 tracks), for threat level two, and for the five-site weapon configuration.

The following conditions define the idealized human solution. Two missile assignment modes were employed: (1) missiles used early on priority targets, versus (2) missiles used only as back-up weapons. Two action rates, three per minute versus five per minute

were employed over both weapon conditions to simulate realistic human assignment capacities. Aircraft were launched either two on one at-a-trail or three on one at-a-trail. If the first fighter made the kill, then the second was permitted to continue on to another assignment. This avoided the rule of lost-fighter probabilities being assigned until the second intercept attempt (cf Appendix I). In addition, fighters not "used up" in trail assignments were not returned to base for rearming, but could be diverted to another assignment. (The commander also had these options in the experimental runs). In every case, assignments were made first against bombers, then against fighter-bombers, then fighters, and then other inputs.

The "idealized machine" solution approach was the same as for "idealized man" except that zero action delay was assumed. The "random machine" or poor machine performance solution employed the zero time delay, but tracks were assigned on in order of appearance and the actions (weapon combinations) were assigned to them at random.

The results of these various solutions are summarized, below, in Table 9. As might have been expected, the zero time delay, "idealized machine" approach was superior in terms of average percentage of kills (93.2 per cent). However, kills by themselves do not adequately describe effectiveness of performance; in every idealizedmachine solution penetrations occurred, and damage was assessed in the majority of cases. The obtained weapon per kill ratio of 2.8 to 1 is of special note because of its similarity to the figure given by the research data. We have already observed that the commanders'

TABLE 9 ANALYTICAL SOLUTIONS TO SAMPLE PROBLEMS

	No. of Tracks		% Kills	KILLS Total	KILLS B	KILLS FB	KILLS F	KILLS O	WEAPONS USED F	WEAPONS USED M	WEAPONS USED Total	Lost	DAMAGE P	DAMAGE F	DAMAGE M	WEAPONS USED/ Kill
SOLUTION (1)	60		100%	60	17/17	12/12	29/29	2/2	67	3	70	18	0	0	0	1.1/1
Solutions Using Missiles on Priority Traffic Early in the Problem																
SOLUTION (2)																
2/1 At a Trail(1 min. intervals)- 3 Tracks Per Min. - B FB F O	60		83%	50	16/17	10/12	24/29	0/2	75	43	118	37	3	2	0	2.4/1
	96	78%	69%	66	27/32	20/21	16/39	1/5	156	60	216	45	22	30	0	3.3/1
	96		82%	79	31/32	21/21	24/39	4/5	176	58	234	48	14	14	0	2.9/1
SOLUTION (3)																
2/1 At a Trail (1 min. intervals) - 5 Tracks Per Min. - B FB F O	60		98%	59	17/17	11/12	29/29	2/2	130	44	174	30	0	0	0	2.9/1
	60	94%	98%	59	16/17	12/12	29/29	2/2	106	36	142	29	5	1	0	2.4/1
	96		89%	85	32/32	18/21	34/39	2/5	200	60	260	62	7	4	0	2.9/1
	96		92%	88	30/32	21/21	34/39	4/5	186	60	246	52	13	18	0	2.6/1
SOLUTION (4)																
3/1 At a Trail (1 min. intervals) - 3 Tracks Per Min. - B FB F O	60	82%	85%	51	11/17	12/12	27/29	1/2	156	45	201	41	3	9	0	3.9/1
	96		79%	75	28/32	21/21	25/39	2/5	243	60	303	71	15	9	0	4/1
SOLUTION (5)																
2/1 At a Trail (1 min. intervals) - 3 Tracks Per Min. - B FB F O Missiles 3/1 Not at a Trail	60	83%	83%	50	11/17	10/12	28/29	1/2	122	45	167	26	5	7	0	3.3/1
	96		83%	80	28/32	19/21	31/39	4/5	206	60	266	70	11	12	0	3.3/1
Solutions Using Missiles as Back-Up																
SOLUTION (6)																
2/1 At a Trail (1 min. intervals) -3 Tracks Per Min. - B FB F O	60		95%	57	15/17	12/12	28/29	2/2	126	42	168	30	2	0	0	3/1
	96	84%	82%	79	31/32	21/21	25/39	3/5	176	60	236	48	14	14	0	2.9/1
	96		74%	71	32/32	21/21	19/39	0/5	158	58	216	49	21	21	16	3/1
SOLUTION (7)																
2/1 At a Trail (1 min. intervals) - 5 Tracks Per Min. - B FB F O	60		100%	60	17/17	12/12	29/29	2/2	124	8	132	32	3	0	0	2.1/1
	60		80%	48	11/17	12/12	25/29	2/2	132	44	176	38	3	1	0	3.6/1
	60	88%	88%	53	13/17	11/12	27/29	2/2	122	44	166	31	2	8	0	3/1
	96		88%	84	27/32	21/21	33/39	4/5	116	60	176	65	7	9	0	2.1/1
	96		99%	95	32/32	21/21	38/39	5/5	174	32	206	49	2	0	0	2.1/1
	96		92%	88	30/32	21/21	34/39	4/5	202	60	262	62	16	12	0	3/1
SOLUTION (8)																
3/1 At a Trail (1 min. intervals) - 3 Tracks Per Min. - B FB F O	60	97%	100%	60	17/17	12/12	29/29	2/2	141	45	186	41	3	2	0	3/1
	96		94%	90	31/32	21/21	36/38	2/5	296	45	341	60	16	14	0	3.6/1
SOLUTION (9)																
3/1 At a Trail (1 min. intervals) - 5 Tracks Per Min. - B FB F O	60		95%	57	16/17	12/12	28/29	1/2	132	45	177	53	2	0	0	3.1/1
Computer (On-Set) solutions																
SOLUTION (10)																
2/1 At a Trail (1 min. intervals) - Missiles as Back-Up - B FB F O	60		83%	50	11/17	11/12	26/29	2/2	128	36	164	37	1	0	0	3.2/1
	60		98%	59	16/17	12/12	29/29	2/2	122	16	138	37	4	6	0	2.3/1
	60		97%	58	16/17	12/12	28/29	2/2	122	16	138	35	3	7	0	2.4/1
	96	94%	99%	95	31/32	21/21	39/39	5/5	194	20	214	63	5	1	0	2.3/1
	96		94%	90	31/32	19/21	35/39	5/5	204	56	260	69	6	2	0	2.8/1
	96		89%	85	28/32	18/21	36/39	4/5	214	60	274	74	7	4	0	3.2/1
	96		100%	96	32/32	21/21	39/39	5/5	200	44	244	64	4	7	0	2.5/1 2.8/1
SOLUTION (11)																
2/1 At a Trail (1 min. intervals) - Missiles on Priority Traffic - B FB F O	60	95%	92%	55	15/17	10/12	28/29	2/2	144	44	188	38	1	1	0	3.4/1
	96		97%	93	30/32	21/21	38/39	5/5	158	60	218	41	5	2	0	2.3/1
SOLUTION (12)																
2/1 At a Trail (1 min. intervals) - Missiles as Back-Up - Tracks Taken in Sequence	60	89%	88%	53	14/17	9/12	28/29	2/2	140	44	184	36	3	0	0	3.4/1
	96		89%	85	27/32	19/21	35/39	4/5	214	60	174	74	7	4	0	3.3/1
RANDOM SOLUTIONS																
SOLUTION (13)																
Tracks Handled at Onset - Taken in Sequence	60		59%	34	5/17	10/12	19/29	0/2	121	45	166	38	7	3	0	4.9/1
	60	55.5%	53%	32	3/17	7/12	22/29	0/2	117	45	162	56	12	6	0	5/1 4.8/1
	96		66%	65	17/32	14/21	33/39	2/5	194	60	254	86	15	9	0	4/1
	96		42%	40	8/32	13/21	16/39	3/5	145	60	205	70	23	23	0	5/1
SOLUTION (14) Using Specific Kill Probability Range for particular Threat Potential of Hostile Aircraft	60		88%	53					118	45	163	27	11	10	0	3/1

Threat

Probability Range	B	FB	F&O
.7-9	17	8	
.4-6	4		21
.1-3			10

terminated the problem series at 96 tracks with just over a 3 to 1 assignment ratio, and with the downward trend still evident.

When missiles were used only as back-up, idealized human solutions were nearly as good (90.5 per cent kills) as the idealized machine. Alternatively, when missiles were used early in the track life of priority targets, the overall kill percentage dropped to 87.7 per cent. This lower kill rate may be accounted for in part by the fact that an extreme range missile intercept automatically incurred the application of one of the kill probability downgrading rules (downgrading of kill probability due to extreme range assignment). This could have a marked effect if it occurred across most of the missile assignments. The overall achieved weapons per kill ratio for this machine series (missiles early on priority tracks) was almost identical with the experimental data at the final load level.

The "random" machine solution yielded the poorest performance. Again the kill figure (55.5 per cent) is misleading in terms of the task to be accomplished. In addition to the low proportion of kills, in these solutions the number of penetrations and amount of damage ran quite high. The weapons per kill ratio of 4.8 to 1, here, is the highest for any solution and is a further indication that "poor" decision performance was achieved by these random solutions.

When total costs are considered for all analytical solutions, it appears that superior performance was gained only at the expense of the second part of the task which the commander had to consider --that of maintaining a weapon posture which could counter additional

attacks.

One other feature needs to be pointed out here also, and that is the risk in using an analytic approach such as this without consideration of the replication problem. While these machine replication runs compare well in general, several extremes in performance may be found, even using the same set of rules, such that the obtained ranges of the order of 24 percentages points were obtained.

Consideration of the experimental commanders' performance on the problems sampled analyticaly is presented, below, in Table 10 and indicates that they turn in a creditable performance, especially when these results are considered in terms of the real-time character of the problems. The average number of penetrations for the 96 track problem is the same for the analytic "human" solution as was obtained in simulated battles. Actual executive performance, however, showed a definite saving in weapon use (188 vs. 227 for "analytic humans"). The greatest number of weapons used in the "good" solutions did not reduce materially the damage score sustained in the analytic runs as compared to the actual human performance.

II. ASSESSMENT OF EFFECTS OF INTERNAL PROBLEM CONDITIONS

One goal of this research was to develop understanding of the decision process. It seems likely that such understanding, if derived from the study of complex executive functions in reasonable simulation of actual battle constraints, might be particularly valuable to the designers of future aerospace threat evaluation and action

TABLE 10

Experimental Commander Performance on Problems Treated in Analytic Solutions

	Track Load 60					96			
	Weapon Sites	% Kills	Damage (W/Lost)	WP/Ratio	Weapon Cost	% Kills	Damage	Cost Kill Ratio	Weapon Cost
Group I	5	65	7	3.5	138	65.6	13	3.0	188
	8	56.6	8	3.4	117	59.3	16	3.2	182
Group II	8	35	12	5.4	114	45.8	18	3.7	163
Ideal Man	5	92.0	2.5	2.8	156	84.6	13.0	3.0	195
Ideal Machine	5	92.6	4.0	3.0	163	94.6	3.3	2.7	230
Random Machine	5	56.0	4.5	5.0	164	54.0	16.0	4.5	230

selection systems. Today, there is a vast growing literature on two-choice decisions without sequential dependence (30). From all this experimental and theoretical work, alternative models of human processing of probabilistic information have been constructed (2, 3). But, there is no way to apply these alternative models to the very complex executive function in surveillance. Before such applications a bridge between theory and the particular empirical domain must be constructed. It is suggested that research of the present sort represents a start toward building this needed bridge. This work aimed to quantify and analyze aspects of actual executive decision-making with the hope that the resulting systematic description of behavior would make possible the application and test of particular models or hypothetical laws.

To initiate the analysis of the effects of the problem variables, four subject commanders were sampled in terms of performance on selected tracks. This selection was designed to provide a sample of damage potential vs. non-damage potential tracks, and early entry into the problems when load was low and weapon inventory was high, versus when load was heavy and inventory partly depleted and somewhat variable.

1. Appropriateness of initial action selection against threat

Table 11 summarizes the initial assignments of the sample of commanders by threat class, damage potential, and time of track entry into the problems.

TABLE 11
Distribution of First Actions for Sample of Commanders by Threat Type & Load

		60				72				84				96						
		B	FB	F	O	B	FB	F	O	B	FB	F	O	B	FB	F	O			
Damage Early	Missiles	3 2								1								3		
		2					1					1						2		
		1																0	5	
	Aircraft	3 5				4	2			4				8				23		Total Early Missile Actions 35
		2 1		8		4	8	5		4	1	2		8	5	4		50		
		1		4			3	8		7	6	13		7	3	20		71	144	
Non-Damage Early	Missiles	3 3		1		3				8				5				20		
		2	1			1				1	1			4	1	1		9		
		1 1																1	30	
	Aircraft	3 6	6	1		9	1			7	7	2		10	4	1		54		Total Early Aircraft Actions 523
		2 2	29	6	1	9	27	14		11	32	12		13	42	10	2	210		
		1		8	1	3		7	1	6	6	21		12	11	32	2	115	379	
Damage Late	Missiles	3 5				7				11				8				31		
		2 3	3			7				5	1	1		9	1	2		29		
		1				1										2		3	63	
	Aircraft	3 8				8				4	2			8				30		Total Late Missile Actions 124
		2 11	3	5		13		2		10	1			14	3	1		63		
		1 5	1	1		6		3		6	3	3		13	2	6		49	142	
Non-Damage Late	Missiles	3 4				4			1	7				5				21		
		2 3	1		1	5	1			7	4	2		12	1	1		38		
		1					1							1				2	61	
	Aircraft	3 5	1		1	2				1				1				11		Total Late Aircraft Actions 300
		2 8	8	2	5	11	5		2	8	6	2	3	6	8		1	75		
		1 1	4	1	3	1	6		2	7	9	8	2	9	9	7	3	72	158	Total First Actions 982
Total Missiles		21	4	1	1	28	3	0	1	40	6	4	0	44	2	6	0			
Total Aircraft		52	52	36	11	70	52	39	5	75	73	63	5	109	87	81	8			
Total		73	56	37	12	98	55	39	6	115	79	67	5	153	89	87	8			

$$62\overline{)178.0} = 2.8 \qquad 68\overline{)198.0} = 2.9 \qquad 80\overline{)266.0} = 3.3 \qquad 102\overline{)337.0} = 3.3$$

Generally, a heavy assignment was made against bomber threats, on first action, as is shown by the column sum of Table 11. Again, there is no indication that learning to discriminate the "real" threat has taken place. Hence, the commander was not able to select out damage potential tracks and concentrate on them, either early in each problem or, for that matter, later on.

The typical commanders' strategy usually was modified for late entry bomber tracks in that missiles were employed with about the same frequency as aircraft interceptors.

Bomber threats increased from 22 to 42 over load, while number of actions (not number of weapons assigned) against bombers, for the sample of commanders, increased from 73 to 153. Weapons committed were usually at the rate of two or three on one. Less than 20 per cent of the actions are on a one-to-one weapon basis on bomber threats.

Fighter bombers were handled by the commanders in a much different manner than bombers. A two-on-one aircraft attack was the most frequent action regardless of damage potential or whether the track entered early or late in the problem. It may also be noted that on initial assignments the most frequently used interceptor was the Red class weapon. This can match the speed and generally the altitude of the fighter-bomber threats. As previously stated, the input speed apparently determines the action selected against the class of threat.

Missiles are very seldom committed against the fighter-bomber

threat, although in this study, the fighter-bomber damage potential was one-half that of the bombers and hence, very important. One-on-one assignments against fighter-bombers were on the order of 22 per cent of the sample.

Fighter threat assignments were, in general, the same as for the fighter-bombers. Fighter inputs increased from 14 to 24 across load while actions committed against fighters increased from 37 to 87; more than a two-fold increase. This increase is general across load, however, in that the initial rate of actions to tracks sampled is 2.8 to 1 and this rises to 3.3 to 1 for the final load level. This is further evidence in support of the concept that "sheer number of tracks" pacesthe subject commanders.

2. Reassignment against threats by class

Out of 979 first actions, 294 had to be recommitted for a second intercept, and 81 required a third action. Negative outcomes fed-back to the commander in this large volume may pose special problems. Threat would appear to go up considerably, while available time to process would be considerably lessened, and available inventory would become progressively less adequate.

Reassignments also became necessary when load within a problem was high. This increased press of the situation might be expected to alter the decision making capability of the commanders. What approach or strategy does he then employ to cope with the situation? Table 12, below, summarizes the actions that were taken on second and third assignment against the sample tracks.

TABLE 12

Distribution of reassigned actions by threat type, load and time interval

TRACK LOAD

ACTION	Salvo	60 B	60 FB	60 F	60 O	72 B	72 FB	72 F	72 O	84 B	84 FB	84 F	84 O	96 B	96 FB	96 F	96 O	N
Second:	3/1	7		1		9		1		19	1	3		12		2		55
Missiles	2/1	5	1	4		16	4	1		8	5	5		19	11	6		85
	1/1	1		1				2		1		1		1		2		9
	3/1	1	1			2		1										5
Aircraft	2/1	7	4	7		5	7	1		5	8	4		8	8	2	1	67
	1/1	3	3	4		10	3	3		3	5	12		11	9	7		73
Third:	3/1	1								3		1		4				9
Missiles	2/1	1		2		3	3	1				2		2	5	4		23
	1/1					1	4	2								1		8
	3/1									1								1
Aircraft	2/1	4				1	2			1	4			1	4	2		19
	1/1			2		5	2	2			3			4	2	1		21
		30	9	21		52	25	14		41	26	28		62	39	27	1	
Total by Load				50				91				95				129		

For second assignment against bombers, there was a strong shift to two-on-one and three-on-one missile assignments. Second assignments against fighter-bombers, also, exhibits a shift to missiles, but usually at only the two-on-one assignment rate. Second assignment against fighters also shows the shift to missiles, across the board. This rate of missile assignment increased as the load increased. Fighter assignments against fighters tended to drop to a one-on-one approach as load increased. Second assignments on other threat tracks at high load have essentially dropped out occuring in only one case. Missiles to aircraft committed were about equally divided for second assignments, and this was also the case for third assignments.

Third assignments on bombers showed either a heavy missile assignment or a low (one-on-one) aircraft assignment. In the latter case the bomber probably exhibited little threat to the sites. Anyway, it has been shown previously that considerable capability remained at the end of each mission and could have been used against this class of threat if the commander had noted danger to a weapon site. Third assignments against fighter-bombers followed the pattern employed on the bombers except that the missile assignments were usually two-on-one. This mode increased in frequency with increasing problem load. Aircraft committed against fighter-bombers were generally in a two-on-one mode. This increased commitment against the fighter-bomber input indicates that the commanders were aware of fighter-bomber threat, but attempted to counter it as cheaply as possible.

on the first assignment, while considerable time remained to act again, if necessary.

Incoming fighter tracks also were assigned against the second time with a heavy missile commitment. This may indicate that threat type was not discriminated well by the commanders, or possibly it may mean that this response is partly an experimental artifact due to the initial appearance of fighters near the weapon sites. The fact that heavy aircraft assignment against this class diminished on second assignment may indicate that some evaluation of threat level has taken place.

The third assignment on fighters also showed a relatively high commitment rate for missiles. When used, however, most of the fighter assignments were of a one-on-one mode for the third assignment. In summary, then, it can be seen that missiles and aircraft are used with about equal frequency for both the second and third assignments.

3. Kill probability sampling for damage vs non-damage and early vs late entry tracks

In Part I, results for kill probability sampling were shown to remain high across the increasing load, in general. In this section, performance against a sample of early and late entry tracks which could vs. those which could not cause damage is sampled for kill probability achieved. Table 13 summarizes these results for the sample of the commanders.

Bombers in general had the higher kill probabilities assigned,

TABLE 13

Average kill probability selected for sample of Commanders by threat type and track load

Damage Potential	TRACK LOAD 60 B	FB	F	O	72 B	FB	F	O	84 B	FB	F	O	96 B	FB	F	O	Row Average
Damage (Early entry)	.61	-	.53	-	.58	.53	.41	-	.58	-	.50	-	.64	.55	.47	-	.54
Non-damage (Early entry)	.56	.61	.44	.30	.61	.55	.50	.20	.56	.54	.48	-	.61	.53	.50	.35	.49
Damage (Late entry)	.56	.49	.43	-	.57	-	.58	-	.58	.49	.48	-	.57	.45	.49	-	.52
Non-damage (Late entry)	.57	.47	.52	.45	.48	.44	.41	.49	.53	.42	.43	.42	.53	.47	.41	.41	.47
AVERAGE	.58	.52	.48	.38	.56	.51	.48	.35	.56	.48	.47	.42	.59	.50	.47	.38	

and this is consistent across the increasing problem loads. Within each problem the difference between early and late entry, and damage vs non-damage bombers, is probably not large or consistent enough to be meaningful.

The average fighter-bomber kill probability that was selected tends to be somewhat lower than for bombers. This holds almost constant across loads. Within a load level, the late entry fighter-bomber showed a slighly lower kill probability selected, although, of course, with this small sample any slight differences might be due to chance.

The average fighter kill probability selected holds constant across load level. There are no apparent differences for kill probabilities selected against the fighter inputs for early vs late entry or for damage vs non-damage tracks.

Actions recorded against the remaining "no damage" tracks show that attempts were made to kill them across all levels of load. The actual number of cases is very small, here, but nonetheless, these actions against hostile, but harmless tracks raise a question of the level of evaluation of threat achieved by the commander. It should be recognized, however, that the task instructions did include the injunction to seek to achieve kills on hostiles regardless of threat status, so the executives were within the ground rules.

These data on damage versus no damage tracks show that the commanders did achieve the correct ordering of kill probabilities for the various broad classes of threat. Actions against bombers

yield a mean probability of .57, against fighter-bombers the figure is down to .50, for fighters it is .47, and for the other tracks it is .38.

4. Damage assessed against a sample of commanders

An examination of total damage assessed against each member of the commander sample may be made to determine whether they achieved a relatively uniform success in this phase of the task or if wide individual differences were present. If one or more individuals developed serious deficiences in action selection technique, one would expect the effect of such inferior assignments practices to show up in this score of damage sustained.

Examination of Table 14, below, indicates that the spread in individual differences was quite narrow considering the complexities of the problems and the potential damage presented. While inter-subject differences were small, threat levels were marked, totalling about a two-fold increase in damage assessed. This is also the situation for increase in track load; hence, it does not appear that total damage was an insensitive measure. The scores suggest, however, that the commanders were able to process the site selection aspect of the problem in either the five or the eight site mode about equally well. In general, these damage assessment results suggest that the selected commanders all attained competence in minimizing damage. Wide individual differences are not apparent, and the damage totals represent only a small fraction of the damage potential that existed.

5. Implications of the results for decision-making viewed as a process

TABLE 14

Per Cent Damage Assessed against sample Commanders by Load and Threat Level

TRACK LOAD

Subjects		60				72				84				96			
		Total Weapons (125)				Total Weapons (135)				Total Weapons (165)				Total Weapons (180)			
		5 Sites		8 Sites		5 Sites		8 Sites		5 Sites		8 Sites		5 Sites		8 Sites	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Threat Level I	A	2	1.6	0	0.0	0	0.0	5	3.7	3	1.8	7	4.2	12	6.7	12	6.7
	B	1	0.8	3	2.4	8	5.9	5	3.7	2	1.2	2	1.2	9	5.0	7	3.9
	C	5	4.0	0	0.0	5	3.7	4	3.0	1	0.6	0	0.0	9	5.0	2	1.1
	D	2	1.6	0	0.0	4	3.0	4	3.0	2	1.2	6	3.6	7	3.9	8	4.4
		M	2.0		0.6		3.15		3.35		1.20		2.25		5.15		4.03
		Total Weapons (130)				Total Weapons (135)				Total Weapons (170)				Total Weapons (135)			
Threat Level II	A	4	3.1	5	3.8	6	4.3	20	14.3	15	8.8	9	5.3	16	8.6	15	8.1
	B	3	2.3	7	5.4	9	6.4	14	10.0	5	2.9	10	5.9	12	11.9	14	7.6
	C	10	7.7	2	1.5	16	11.4	8	5.7	14	8.3	11	6.5	23	12.4	19	10.3
	D	4	3.1	10	7.7	13	9.3	30	21.4	13	7.6	20	11.8	25	13.5	17	9.2
		M	4.05		4.60		7.85		12.85		6.90		7.37		11.60		8.80

It may be suggested that performance of the decision-making tasks in this set of problems involves two different levels of judgment: (1) it is necessary to make an appropriate action choice against each individual track, and (2) the executive has to evaluate the resulting set of momentary judgments in the context of the developing problem. This second level of judgment may be thought of as an examination of the success of the strategy being employed and possible selection of some altered assignment rules. Obviously, its optimum performance should be based on all the information elements available since all are known to be relevant to prediction of the future progress of the problem. In addition to the information presented dynamically on the various displays, which may govern the individual scramble assignment to a large degree, the strategist should consider the problem ground rules, the advance intelligence information, and successes and failure recalled from earlier problems.

It is the impression and belief of the team of investigators that the commanders did, in fact, perform this second strategy evaluation and modification level of judgment. Using the information elements listed, above, the commanders appeared to have modified the strategy and approach to solving problems, particularly with respect to points such as the initial use of aircraft weapons (the approach that was developed in many of the training runs and which may have been related to the commanders' prior experience in air defense operations).

Analysis of the debriefing data suggests, however, that decision-making at the strategy level is not entirely a conscious process.

Particularly, this impression may be gained from the lack of descriptive accuracy in the commanders' verbal reports of success. Initially, the reports of adequacy of performance were too optimistic. Commanders believed that they had done better than the objective measures of performance indicated. They also overestimated the accuracy and utility of the briefing and intelligence data, which was available to them during the problem runs only in the form of memories. At the end of the experiment, however, commanders' estimates had become better descriptions of the facts.

What now can be said about the nature of the decision process studied in these problems? Three major features appear to characterize the process: (1) dynamic sorting of categories was continuously required in terms of threat, counter weapons and locations, rule structure, and other data that had been provided; (2) there was dynamic or on-going weighting of alternatives selected in terms of the overall outcomes desired; and (3) there was partial lack of awareness or at least inability to verbalize reliably, how these processes occurred.

From the two kinds of analysis of results presented in this section, it seems that the commanders handled items one and two quite well in terms of sorting for threat, which was elementary in this case. This is indicated by satisfication of the matching criteria, selecting of armaments, yielding appropriate kill probabilities, assignment of priority to the tracks, and failure to process but a very small percentage of the total number of tracks. While doing the above,

commanders were able to select reasonably short intercept times, and to use single intercept weapons (A/C) advantageously, so that they would return to inventory in time to be ready for second intercepts. Also, they were able to work efficiently in spite of the two ground rules which might have reduced kill probabilities. This efficiency extended in the maximum load levels to the point that they were experienced enough to achieve kill probabilities equal to or better than those achieved during the low load problems. Another procedure the commanders exercised more and more was the use of missiles when load dictated and faster outcome feedback was necessary.

The relatively slow development of an accurate appreciation of fairly crucial information elements in these problems suggests a general point believed to be of some importance. This point is that when you are dealing with complex decisions such as those of the military executive, a very great deal of practice and experience is to be desired. Most classical experiments in decision-making have used tasks of such simplicity, e.g., "guess which light will come on next, the left or the right," that a beginner might quickly learn to do as well as an old hand. But this is not the way decision tasks of importance are encountered in the real world. True, we have to decide which shoe to put on first each morning, but a very simple strategy will suit the problem. Crucial human roles in surveillance systems are quite different. They call for exercise of a higher level of judgment. Thus, the principal accomplishment of this study may be that it has provided some baseline data to show that a fully trained, highly selected human

executive can perform well, judged by comparison to various machine or analytic problem solutions, in higher order decision functions, despite task load factors of very considerable weight. From the vantage of these empirical statements, it should be possible to probe the the effects of a number of procedures and experimental factors believed to be relevant to complex decision processes. Additional studies in the present program have been designed with that goal. Particularly, the effects of error and system noise, in general, are thought to be worthy of study, for the reason that some degree of unreliability of surveillance data always obtains, and costs go up sharply when noise reductions are demanded. To make design tradeoffs on a rational basis, it is necessary to develop a decision technology that takes account of the implications for decision effectiveness of the various categories of input and processing errors. Those studies remain to be performed.

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APPENDIX I

PROCEDURE:

The general task of the commander or decision maker in this experiment was fourfold as follows:

(1) To minimize the damage to the weapon areas

(2) To destroy a maximum number of threatening vehicles

(3) To conserve counter weapons so as to consume a minimum of forces consistent with objectives (1) and (2) above

(4) To develop his own strategy under constraints imposed by the ground rules.

Two basic certainties existed in this study; the commander knew that he could depend on (1) highly reliable surveillance data and (2) a reliable assessment of the action outcomes. Two basic uncertainties also existed, in that, (1) the threat intelligence data was presented over a range of probable values, and (2) there were variable kill probability outcome distributions for the weapons. To a lesser extent. uncertainty existed in the selection of the variable outcome times. The commander knew the range of outcome times possible, and as a sub-task, he had to select weapons which would yield an overall minimum intercept time.

A. Threat Vehicle Types

In the present experiment there were four broad categories of threatening vehicles, all of a conventional air-breathing sort.

There were:

1. Bomber Threats - There were three categories within this class:

(a) High Bombers - This group includes bombers of high mission speeds (800 knots) as well as high altitude (65,000 feet). These might be countered only with interceptor missiles or "Green" class fighters.

(b) Medium Bombers - This group of vehicles includes bombers whose altitude limit is lower (55,000 feet) and whose mission profile speed is 700 knots. The appropriate classof manned interceptor is the Blue type. Green class fighters may be committed against this class input, but they would be normally considered an overmatch. Again, all ground-to-air missiles may be used.

(c) Low Bombers - These vehicles have an altitude capability of 45,000 feet and speeds of the order of 600 knots. The matching class fighter is the Blue type, but the Red infrared seeker missile armed fighter could also be used. Ground-to-air missiles also might be used.

2. Fighter Bombers - There was one class of fighter-bombers: speed was 500 knots and altitude ran to 45,000 feet. Ground-to-air missiles could be used against this class threat and all fighters with the one exception of Red machine-cannon armed class (these are restricted to 40,000 feet altitude).

3. Fighters - Threatening fighters were of three classes:

(a) High--65,000 feet, 800 knots

(b) Medium--55,000 feet, 700 knots

(c) Low--25-50,000 feet, 500-600 knots

4. Other threat-labeled tracks - There were two classes of additional tracks in this category:

(a) Reconnaissance vehicles - 65,000 feet, 900 knots

(b) Troop and cargo transports - to 25,000 feet and 300 knots.

B. Counter Weapon Types and Sites

The counter weapons available to the commander were of broad types: missiles and interceptor aircraft. These were located in either a five-site or an eight-site distribution. The forward, or enemy ward, were designated airfields one and two. Airfield two was deleted in the five-site mode. Red class fighers (of somewhat restricted capability) were the only counter weapons that were deployed in these locations. The intermediate sites some distance directly behind sites one and two were designated as airfields three, four and five. Airfield five was deleted in the five-site mode. The rearmost areas were designated missile areas A, B and C. Missile site C was deleted in the five-site mode. In the initial instructions it was pointed out to the commanders that while the five-site configurations may appear the easier of the two modes, the threat from a penetration has now nearly doubled and, hence, it may be much more difficult to insure survival of his weapon capability.

The two tapes (containing the digital inputs) provided two different penetration directions on per tape. The commander was briefed

in terms of the expected strike routes for the main hostile thrust. This was from right to left across his display for tape I, and from upper left to lower right for tape II -- the more complex tape in terms of threat complexity involved. (Site orientation toward "North" or upward on the display, was not under consideration in this experiment).

1. Ground-to-Air-Missiles - These weapons were of relatively low yield, requring proximity contact. They were employed in two modes:

(a) Long range -- In this mode, the missiles could reach a target anywhere in the situation domain. Intercept times ranged from one to seven minutes. One, two, or three missiles could be launched per salvo.

(b) Short range -- The range in this mode was restricted to targets penetrating a fifty-mile diameter circle surrounding the site. If an action order was pending, the missiles were launched at penetration time. Intercept feedback time was one minute. A maximum of three salvos of three missiles each could be launched against a target. The assumed "missile command" had the same digital track information, but had no autonomous control and was to operate only under the direction of the area command in these exercises. To this end, decommit queries were sent from the missile sites, when in the short range mode, to the commander when a track under this assignment mode had faded.

Only three automatic missile operating conditions were possible:

(1) Missiles assigned to low-priority targets would "hold fire". if a prior aircraft assignment was being pursued into the missile site until outcome of this previous assignment became known. This rule was voided when a priority target also under assignment penetrated the missile site.

(2) A long range guidance mode would convert and fire, as in short range mode, when its assigned track penetrated.

(3) A three salvo sequence automatically fired until a "kill" is registered or the sequence is completed.

2. <u>Interceptor Aircraft</u>

(a) Green class fighter (65,000 feet) -- This was a special high performance interceptor. It operated at 800 knots average profile speed and could climb to 65,000 feet altitude at approximately 40,000 feet per minute. It was restricted to one intercept before returning to base for more fuel and weapons. However, after a 15-minute delay a previously used Green class fighter was available on ready status for scramble again. These inerceptors carried one of three armament systems: machine cannon, infra-red seeker missiles, or an all-weather system. Green was the matching class for high performance threats and the fighers were found at airfields four and five only.

(b) Blue class aircraft (55,000 feet and 700 knots) -- This was a general purpose vehicle which could remain airborne for the life of the problem and could run repeated intercepts on the basis of ample armament and fuel stores. Thus, this weapon could be diverted from an airborne station immediately after an intercept attack.

The three armament systems listed for Green also apply here. These aircraft were based at airfield three, four and five.

(c) Red class aircraft (40,000-45,000 feet and 600 knots) --These were small interdiction weapons operating out of two forward area dirt strip configurations. They were released to the commander for any necessary defensive operation. They could fly only one intercept mission, and they had to RTB for rearming and refueling. They were armed with either a machine cannon configuration or IR rockets (the service ceiling was 40,000 feet when the machine cannon mode was employed).

C. Scoring Procedures

In general, where "matching" class fighters or ground-to-air missiles are assigned by the commander, scoring presents no problems. An "undermatch" (assignment of a Red class weapon to a threat for which the matching class is Green, for example) is scored as a miss. Overmatching, as described above will ordinarily increase kill probability and yield a slight advantage in intercept time. The commander was not penalized for overmatching by the scoring procedure, but ran the risk of using-up these weapons on lower level threats is used indiscriminately.

Each possible action outcome had to be established and located in a readily accessable form for the referees so that these referees could provide to the commander the evaluation resulting in dynamic feedback of action outcomes during the course of the tactical problems.

D. Weapon Assignment Modes and Procedures

One of the most important points to be remembered concerning weapon assignments, aside from selection of appropriate weapons, is the standardization of the assignment message format. Standardization in this respect is of the utmost importance from the experimental, as well as from the practical, operational point of view. Experimentally, only standard messages can be handled with the required speed and accuracy by the clerks and referees. However, convenient a non-standard message is to the commander, it slows down or confuses the execution of the assignment resulting ultimately in penalty to the commander. In addition, future systems will require communications with machines in language that the machines can understand. Non-standard messages are understood and executed even less well (i.e., not at all) by machines than by men (as in the present experiment). Therefore, an essential part of the procedure is the use of rigid, but efficient message formats. The assignment message consisted of the track number assigned against, the weapon kind to be used, the site to be drawn from, its armament category, the number to be used, and an indication of priority of the assignment on a four-point scale (e.g., Track 84, Green three, two IR's, priority one).

Weapons may be assigned one, two, or three at a time against individual threats. In addition, "trail" type assignments of two or three successive aircraft or missiles may be used. If the first aircraft kills, the rest go to airborne-available status. In the case of the missiles, all are fired and detonated regardless of an initial kill by the first weapon. Due to the actual vagaries of surveillance data and

close control performance (i.e., a prior failure of control might still add data to improve a subsequent attempt), trail type assignments generally result in higher kill probabilities, overall.

Kill probabilities for Green type aircraft varied from .2 to .8, depending on number assigned, armament type, delay in assignment, or distance to go. Blue class was .2 to .8, and Red class .1 to .8. The more weapons assigned (up to three, either together or in "trail",) the higher the potency of the armament, and the sooner after onset of the threat the higher the probability of kill.

The commanders were given the following operational ground rules to govern their deployment of the counter-weapons:

1. Scramble on all hostile tracks,

2. Scramble on unknowns as hostiles after the unknowns had been carried by the system for one minute.

3. Apply matching criteria by assigning a weapon combination that can make the target altitude and is reasonably close to the target's speed.

4. Indicate the priority of each assignment as follows: Bomber designated as 1, Fighter-bomber as 2, Fighter as 3, and other categories (cargo, troop, and reconnaissance) as 4, except where the commander wishes to indicate the downgrading of certain assignments to indicate their presenting a lesser threat.

5. Weapon assignment permits one, two, or three aircraft or long range missiles to be committed on any one track per assignment (except for the short range missile mode--where a maximum of

three missiles and three salvos may be committed). Unlimited successive assignments per track are permitted, but the commander must issue a new scramble order for each new assignment.

6. Observe progress of friendly traffic. If a scramble is assigned inadvertently, the commander will receive a decommit query.

7. Missile interceptors. Intercept time for the long range mode range fromone to seven minutes. "Target going-out-of-range" signal will be fed back in four minutes. In the short range mode, firing can commence anytime after perimeter penetration, but kill probability will be reduced by .1 if the assignment occurs over five minutes after penetration.

8. Interceptor aircraft. Intercept times will range from three to twenty minutes. A "too-late-to-make intercept" signal will be given 10 minutes after scramble if the target will be out of range in 20 minutes. A "tail-chase" signal will also be given in 10 minutes (four minutes in some special cases) if the intercept will result in an impossible tail-chase at 20 minutes.

9. Damage assessment:

(a) Bomber penetration (defined as 25 miles from site) will cause loss of one-half of the weapons at that site at timeof penetration (weapons on the ground only).

(b) Fighter-bomber penetration will cause the loss of one-fourth of the ground-based weapons (penetration radius same as above).

(c) Fighter penetration will cause the loss of one airborne weapon, if any. In some cases it will be a weapon on the ground that

is lost, or in some cases it will be a missile, if a missile site is hit.

(d) Whatever penalty is appropriate will be assigned at three minutes after penetration, with a few exceptions where a longer delay is introduced. The commander will be notified by a priority message, and also the loss will be posted in the appropriate location on the status boards.

(e) Damage can occur if Initial Point is reached before kill time (although post-drop intercepts are possible.

(f) Hostile drop success was stated at..8 (but was not applied).

(g) Site evacuation procedures:

1. Evacuation to CAP will not be permitted until site penetration is pending, on the grounds that the system will tend to become loaded and the value of the dispersal at the fields would be lessened thereby.

2. On evacuation, aircraft will be flown off at the rate of three per minute with normal scrambles still permitted until all aircraft are launched.

3. In the case of short mission profile weapons, they will orbit 15 minutes and then return to base. If two drops have been successful, the site will be closed out and the weapons will RTB to their companion site, if intact. If not, they will be staged to the nearest rearward area.

(h) System performance confidence in terms of detection, tracking, identification, and communications are 100% at the start of the mission.

E. Intelligence Briefing

The commander was instructed that previous intelligence and surveillance data indicates specific threat-type activity at several hostile locations. On the basis of these and other previous data, an estimate of the expected hostile commitment could be made. However, intelligence might not be aware of new areas of activity, so only gross estimates were quoted to him. The table below indicates the distribution of estimated threats, confidence limits of these estimates, and the actual threat presented for each mission. The commander was briefed on only the estimated threat and its confidence level, in terms of expected commitment rates. Also, during the briefing, the commander was given, for review against the expected threat commitments, the exact distribution of weapons available for use in the mission, (See additional table below).

F. Pre-mission Training

Each commander had seven runs (through a 96-track problem) with a two-site weapon problem. The missile and fighter-interceptors were located at only the two bases, and hence, the problems were simple in that only two bases required protection. Feedback on intercept outcomes was provided at a constant time after assignment (six minutes), and the range of probabilistic outcome values was not extensive. The values ranged only from .45 to .99 for the weapons under the commanders control or .1 for an automatic missile fire mode over which he had no control. The latter mode yielded some additional kills thereby providing the commander with the option to decommit

weapons previously assigned as no longer necessary against a killed track assignment.

The second phase of training consisted in presenting a more complex level of problem. Eight weapon sites were now employed, consisting of five aircraft and three missile sites. The automatic missile firing feature was dropped, and the commander now had to generate all weapon assignments. At this time the broader (from 0.0 to 1.0) distribution of probabilistic outcomes was introduced along with variable outcome times for a more realistic feedback of results of the commanders action selections. This tended to force the commander to sharpen his tactics to preclude choosing assignments with low payoff. The commander had to pay much closer attention to all information sources provided. The commanders actions at this level of problem complexity were processed by the introduction of the pre-programmed referee sheets. Some debugging had to be done, procedures changed, and level of skill developed by the referees to service the commander as he progressed from loads of 24 through 72 tracks. On some occasions, when the experimenter felt some commanders needed more practice or were in doubt about some of the rules, additional runs were required to bring individuals up to the general level of performance.

TABLE 1

Actual Threat and Estimated Potential Threat to Commander at Pre-mission Briefing

		Problem Load Level							
		60 Tracks		72 Tracks		84 Tracks		96 Tracks	
	Category	Actual Threat	Potential* Threat	Actual Threat	Potential Threat	Actual Threat	Potential Threat	Actual Threat	Potential Threat
	Bomber								
	High	3	5	10	20	11	20	11	20
	Medium	10	10	8	15	13	25	13	30
Threat	Low	1	5	6	10	0	5	6	10
Level	Fighter-Bomber	16	30	14	25	16	30	20	40
I	Fighter								
	High	1	5	0	5	1	5	1	5
	Medium	8	15	10	20	14	25	4	25
	Low	13	20	13	30	18	30	20	40
	Bomber								
	High	13	25	16	30	18	35	21	40
	Medium	4	10	8	15	12	25	13	30
Threat	Low	0	0	0	5	0	0	0	0
Level	Fighter-Bomber	12	25	15	30	18	35	21	40
II	Fighter								
	High	10	15	8	15	10	20	12	25
	Medium	11	15	14	25	13	25	15	30
	Low	10	15	11	20	13	25	14	30

*Prior to each mission, the commander was told that the expected threat for bombers and fighter bombers varied over a range of 30 to 70 per cent of the potential threat, and that the range was 40 to 60 per cent of the figher potential threat.

TABLE 2

Distribution of Damage Potential Tracks by Load and Threat Level

		TRACK LOAD			
		60	72	84	96
		Hostile Track Load			
		52	61	74	85
THREAT LEVEL I	**Threat Type**				
	Bomber	4	7	6	8
	Fighter-Bomber	1	0	1	2
	Fighter	10	3	11	12
		15	10	18	22
		Hostile Track Load			
THREAT LEVEL II	**Threat Type**	60	72	84	96
	Bomber	4	10	12	15
	Fighter-Bomber	0	2	0	2
	Fighter	11	13	17	20
		15	25	29	37

APPENDIX II

SIMULATION FACILITY

This appendix provides a functional description of the equipment utilized to prepare and prosecute this experiment, details of the track situation, and the experimental design that organized the data collection.

A. Equipment

1. Analog equipment description:

(a) Moving Radar Target Generator, 15-J1C(modified)

The moving radar target generator was used as a new video information source for the simulated situations in the problems. The signals simulate moving aircraft or missiles, the speed ranges being dependent on the scale factors used in the system. Initial starting point, speed, course direction, and rate of turn are inserted manually. Antenna rotationinformation is furnished by the antenna rotation simulator to these devices as well as the video graph, AN/UPA-35, and the Cartrac Common. Since the Cartracs had a display coverage of 150 miles radius, and the digital display gave a 300 by 300-mile presentation, many tracks had to be converted by off-setting on analog to digital conversion in order to utilize the total display area of the digital system.

(b) PPI radar scope AN/UPA-35

The AN/UPA-35 is a monitor scope used with the 15-JIC's when recording tracks on a magnetic tape to prepare a mission. In this process the monitor scope was used to check the azimuth, range, and velocity of each individual track.

(c) Radar indicating equipment (Video Graph)

The Video Graph (V.G. scope) is similar to a regular PPI scope except it used a "dark trace" CRT and an optical projection system for displaying the images on a horizontal viewing screen. The surface was covered with tracing paper upon which the mission tracks were plotted in real-time. Thus, a hard copy record of the track histories became available for analysis. The Video Graph equipment is self-contained requiring only video, trigger, and antenna rotation information.

(d) Cartrac common

The cartrac common was used as a buffer unit between the radar simulation equipment and the cartrac consoles. It supplied the sawtooth wave voltages needed for coordinate conversion, provided synchronization between the antenna rotation simulator and the cartrac, and peaked and amplified the video information.

(e) Cartrac console

Each cartrac (cartesian tracking) consoles consists of a PPI scope plus twelve channels, each of which was capable of tracking a single target. The electronic gate of a tracking channel (normally 3 miles square) was assigned to a target manually by means of a "joystick". First, the operator positioned a spot on the desired blip by moving the joystick, and then he assigned a particular tracking channel by specific motion of an assignment switch. An automatic correcting circuit in the assigned cartrac channel then kept the gate positioned so that the target was automatically tracked. The output for each channel, which is in X-Y analog form, was then sent to the

coder for conversion to digital form.

(f) Movement identification officers (MIO) console

The MIO console was used in conjunction with the data assignment panel to indicate the status of the twenty-four tracking units. Individual cartrac gates may be identified by two methods: (1) depressing a numbered button corresponding to the number of the tracking channel, and (2) by placing the digital spot on the PPI on the gated target to be identified. Numbered lights are used to indicate the status of a cartrac unit, i.e., hangared, tracking new target, or tracking with auxiliary data assigned.

2. Digital Equipment Description:

(a) Data assignment panel (DAP)

The data assignment panel provided a means to insert, manually, an identifying number (tag number), altitude, speed, information, target type (category and IFF identification), and a personal identification number. All data other than height and speed were fed to the coder in a digital format. The two exceptions, height and speed, were set by potentiometers and converted to digital information in the coder.

(b) Tape recorder

The tape recorder used was a dual-channel, Model 350, Ampex Recorder. One channel contained timing pulses used for synchronizing data flow, and the adjacent channel contained problem data.

(c) One-hundred target tape generator

The one-hundred target generator was developed

to control the flow of data between the recorder and the rest of the system. It took the timing pulses from the recorder and sent a data transmission signal to the digital communications unit to record. This was necessary because targets were generated in blocks of 12, and the problem tapes for this experiment contained 96 targets. A set of switches determined which time slot on the tape was being recorded. This same set of switches allowed the experimenter to select numerous combinations of target loads during playback. This device may be considered the heart of the system.

(d) Coder

The coder was essentially an analog-to-digital converter. It accepted the analog gate voltages and converted them into a digital message format. This format also contained auxiliary information that had been inserted through the DAP. A target message consisted of five words, each word containing ten digits.

(e) Digital communications unit

The function of the digital communications unit was to provide timing signals to the coder and to the drum storage unit. These signals were needed for the formation of the digital messages in the coder and to control the record-playback circuits in the drum storage unit.

(f) Drum storage unit

The purpose of the drum storage was to store the position and auxiliary data in a manner suitable for visual presentation. Digital to analog conversion circuits were included in this unit for the X-Y position voltages needed by the CRT deflection plates

and there were matrices for binary to octal conversion of the auxiliary data.

(g) Digital display unit

The digital display consisted of a cathode ray tube, with a long persistence phosphor, and in-line display for the display of auxiliary information. The system cycling time was sixteen seconds. The long persistence phosphor left a "trail" and gave a visible history of the tracks. An overlay was used to indicate geographical features and military targets, such as bases and other areas to be defended.

Auxiliary data was called up for display by aiming a light gun at a particular target and squeezing the trigger button. When this was done tag number, velocity, altitude, category, and personal identity appeared on the in-line display. It was also possible to display all target position blips of one specific category; i.e., fighter, fighter-bomber, etc., or one particular identification class, eliminating from the main display surface all other blips.

(h) Digital clock

The digital clock was used to provide a source of displayed time to use as a reference base throughout the mission. The sixty-cycle power line or timing pulses stored on one channel of the tape could also be used as a timing source. Several clocks synchronized to a master unit were used to insure a common time base in refereeing and data collection.

3. Anciliary Equipment:

(a) Status boards

Plexiglas tote boards were used to keep a running

account of the weapons inventory during the missions. They consisted of edgelit boards with a total area of approximately thirty square feet. Information was displayed by writing on the backs of the boards with colored grease pencils. (cf diagram at end of this Appendix).

(b) Communication system

The telephone system consisted of a power supply, distribution cabinet, and several AN/GTA-6 telephone boxes. The arrangement was flexible, capable of being used for communications between the operator and the refereeing section and among the referees and status board operators.

B. Experimental Problem Preparation

1. Track Situation Recordings

(a) Recording procedures

Tapes were generated, in units of twelve targets, eight successive times to give a total of ninety-six targets per tape. Position information, in polar video form, was generated by the radar simulators and sent to the cartrac common, AN/UPA-35, PPI scope, and the Video Graphic scope. The cartrac common then re-transmitted this information to the cartrac and MIO consoles.

Operators at the two cartrac consoles manually assigned tracking gates to all the targets. A tag number and auxiliary information for each such track was then inserted at the data assignment panel by an operator who used the MIO console to call up the identifying number of each individual track and gate as it came into view on his PPI.

The digital coder converted the X-Y analog position voltages of

each tracking gate to digital form. Height and speed from the auxiliary data panel were also converted to digital form in the coder. The coder then built these into a message structure for each target and sent them to the digital communication unit.

Timing pulses from the tape recorder were sent to the 100-target generator which in turn sent a data transmission signal as previously discussed. When ordered, the digital communication unit sampled the coder and transmitted the message to the tape recorder, where the information was recorded in the proper block of the tape.

Two basic tape recordings of track situation and auxiliary data were prepared for the experimental runs to be used for data collection purpose. A third tape was prepared for training and system checkouts. Each tape contained 96 complete tracks. The proportion of tracks of different types will be found listed below. Description of the characteristics of different classes of threatening tracks and friendlies may be found in Appendix I.

During track generation, the targets were manually plotted on the V.G. indicator to monitor how well the simulator crew followed the problem scripts. Since many errors could be introduced to the data stored on the magnetic tapes from mis-alignment of the simulators, perturbations in the cartrac tracking, errors in use of the data assignment panel and subsequent noise in the digital system, it was necessary to check all aspects of these stored data.

Constitution of the situation tapes by numbers of tracks:

Hostile	Tape I Training	Tape II Data	Tape III Data
Bomber	22	31	34
Fighter-Bomber	27	20	21
Fighter	23	31	38
Other tracks (recon., Troops, & Cargo)	2	3	3
Friendly			
Bomber	7	4	0
Fighter-Bomber	13	4	0
Fighter	2	3	0
Other tracks (recon., Troops, Cargos)	0	0	0
	96	96	96

(b) Data check-out

Three methods of data check-out were employed, in addition to perusal of the track plots on the V.G. indicator as follows:

(1) Variplotter -- After a tape had been generated, it was played back into a high speed read-out and graphical recording instrument at an eight-to-one speed ratio. This was done for all tracks since a small error could mean the difference between penetrating and not penetrating a defined target area. On repeated rerun to sample tracks (both tracks that followed the original script well and

others that had system noise introduced during recordings), the spread around most position points very seldom exceeded two-and-one-half miles. (This small error can be accounted for in the mechanical back-lash of the variplotter itself.) This recording also furnished a hard-copy of the taped track, a record which was used later to score all possible intercept combinations.

(2) Computer -- Since a computer program was available from another effort (24), it was felt desirable to play these mission tapes into the computer and sample the stored digital information independently on the playback elements of the tactical system. The first run sampled the position data on each track for every other (odd) system cycle. The second run sampled all the stored ancillary data. Whenever doubt arose about any of the track data, the computer record was used to resolve the issue.

(3) Error check during mission -- In addition to the above error checks, it was necessary to assess system performance during playback of each mission. To this end an experimenter recorded the tag and ancillary data associated with each action that was reported and also for most of the track interrogations. This record was then checked against the preprogrammed data. Error was calculated to be less than one per cent. Alignment error was constantly checked by an experimenter during each mission to insure that site penetration occurred as planned.

2. Action outcome scoring:

(a) <u>Computation of intercept points and outcome delay times</u>

Intercept points were computed from each applicable

missile and aircraft site for two time intervals of track life (action assigned during the first five minutes of track life and action assigned after five minutes). The basis for this computation was the least time intercept based on the position data from the variplotter. Consideration was given to climb-out and positioning problems associated with each armament configuration. The gun-armed fighter, for example, had to be close atrail for a successful quartering stern attack. The IR-seeker, missile armed aircraft had to be positioned for a snap-up tail-cone or trail tail-cone attack, but could be much further astern and still permit the IR missile to kill. The All-Weather system interceptor assumed capability to attack successfully from any quarter, given reasonable positioning. In the case of the missile (long or short range mode) any attack angle was possible and the intercepts were so scored. Intercept time for aircraft ranged from three to twenty-minutes and from one to seven-minutes for missiles.

Tail chases intercepts were terminated after twenty-minutes. A signal was sent to the commander ten-minutes after assignment on any intercept that was detected to be ending in an impossible tail chase. This "probable miss" signal was sent at ten minutes, and was also sent on actions which would be "out-of-range" in twenty minutes. The commander then could decide to continue engagement or he could decide to decommit.

(b) Generation of weapon-kill probability distributions

Probabilistic outcome values were assigned to each action outcome to provide operational realism, and also, to give a range of

values of the actions selected. These values then could be used to provide part of the basis for evaluation of the commanders performance in selecting appropriate actions. The outcome values were varied as a function of kind of weapons chosen, kind of armament, number assigned, time assigned, and time remaining to intercept. These conditions provided a large distribution of action alternatives which presumably was searched by the commander before he made his action choices. This search was to be made within established rule structure provided by training and instructions.

To make general statements about commander's performance in search of the action alternative domain, it is necessary that the probability outcome for each action be the same for all subjects. That is to say, for each time the "ith" weapon combination is selected, the subject in question will get the same binary outcome (kill or non-kill). Thus, each outcome will influence the total in a systematic rather than a random fashion. Each subject will get the same result each time he decides to use a particular combination.

The use of "static" outcome distributions also expedites the refereeing process. Since an average of around 100 action combinations of assignments were possible for each track, a ready-access program was necessary to provide the "real-time" servicing of the commander's action choices. This large distribution of "possible" actions also precluded any significant learning by the commander, e.g., that a particular choice in the sequence will always kill or fail to kill.

To establish this distribution, a table of kill probabilities ranging from .2 to .9 (in steps of .1) was generated by drawing 1000 samples at

each probability value from the random number tables of the Rand Corporation. The .1 probability level was generated by reversing the outcome for the .9 value. First, the observed value was calculated for each 100 unit sample for each probability value, and then the grand mean was calculated. The range and mean for each probability value are listed below:

TABLE 1

Range and Mean for Each Probability Value Sample

Probability	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Range	0.14	0.28	0.31	0.45	0.54	0.65	0.76	0.90
	0.28	0.40	0.49	0.53	0.69	0.81	0.90	0.97
Mean	0.20	0.315	0.417	0.488	0.596	0.703	0.809	0.933

The probability outcome for each action then was applied to the referee sheets for each track as follows: If the weapon could match the hostile, three successive samples of the one, two, or three-on-one weapons per salvo were permitted when assignment was early enough to achieve maximum kill probability. This was repeated also for the second interval scramble (later than five minutes of track life). This sampling was repeated across armament configuration for both missiles and aircraft.

(c) Referee scoring procedures

The role of the referee action (outcome-feedback processing) will be apparent if two representative actions are followed through processing to final outcome. Events such as mis-matches are obvious -- the weapons are scrambled, show on the board as

as committed; then, after ten-minutes, the commander is informed that the action failed because the weapons were not able to reach their target. Such mis-matched weapons then were placed on airborne-available status.

It may be assumed the commander then would decide to re-assign against that track. His action order might be "Track 73, C-L3, Priority 1." This order designated the track number, directed that three missiles be committed from missile site C in the long-range mode, and stated that this was a first priority target under attack. The scramble recorder logged this information on a buck-slip, along with the time of the assignment, which he read from a digital clock to the nearest second. He passed the buck-slip to the weapon-status clerk, who called the weapon-commitment board to reduce missile site C by three missiles. Then the weapon-status clerk passed the buck-slip to the appropriate aircraft referee. This referee entered the missile assignment on the track referee sheet for future reference, e.g., in case he received a subsequent fighter assignment on this track. If one occurred, he checked the missile-assigned board to determine outcome. If the track was indicated as already killed, he returned the fighter to airborne-available status. If the outcome was negative, he processed the outcome in normal fashion.

When the missile referee received the buck-slip he immediately posted the track in the priority one column, under missile C, and reduced the total of weapons at that site by three to indicate that the missiles had been fired. The outcome was processed, and at intercept time this outcome was indicated by scrubbing the track from the

missile assigned board. At this point the close-out clerk removed the particular track from the system digital display to indicate a kill and sent a chit indicating this kill to the commanders technician for relay to the commander upon request.

In the case of a fighter assignment, the sequence would be as follows: The commander might report, "Track 73, Green 5, IR2, Priority 1." This would indicate that he wanted two Green fighters armed with IR rockets to attack from airfield five. The scramble recorder logged this message and the time issued, then handed the buck-slip to the weapons-status clerk. This clerk called the weapon-commitment board and reduced the IR-rocket capability at Green five by two and also indicated on the buck-slip that one aircraft was pre-programmed to be lost as a result of the engagement. Lost fighter probabilities due to engagement were .5 for Red, .3 for Blue, and .2 for Green. He then passed the slip to the appropriate aircraft referee.

Aircraft referee number two had responsibility for the upper half of the track numbers, so he processed the assignment. He recorded the time on the referee sheet for later scoring purposes, added the intercept time (11 minutes) to the assigned time, indicated that the outcome was a kill, and added twice the intercept time to the assign time. This last step served to indicate that this weapon should go into the turn around position on the status board to simulate the time delay for rearming and refueling. A small chit then was passed to the close-out clerk who was responsible for sequencing these slips for track close-out at the proper time. Also he would send a notice to the commanders technician to indicate a kill. The initial buck-slip

was returned to a weapons buffer storage clerk who held it until the time indicated to tote the lost fighter. Then, the buck-slip was passed to the weapon-status clerk, and he posted one lost IR weapon at the Green five airfield location. The clerk who arranged the slips in time again held the buck-slip until the turn around time indicated. Weapon status was notified at that time and posted a Green five IR weapon in the turn around position. The commander was aware that after fifteen minutes in this location the weapon would return to ground-available for further usage.

C. Experimental Design

The first major experiment was planned to consider action selection performance in a situation providing reliable surveillance data and reliable outcome processing. Of course, decision performance can be expected to be degraded by any unreliability that may enter the information processing sequence. But, before initiating experimental work with false tracks, incorrect identity information, or any of the other "noise" factors that may be expected to creep into any real surveillance system, the first experiment was directed toward the task of furnishing "baseline" information decision success. In a way this might be thought of as a search for normal decision-performance before bringing in "gremlin" factors that past experience had shown may crop-up in battle.

Since previous studies had not furnished a secure base from which to predict the effect of load stresses upon performance in a decision situation approaching the present one in level of complexity, the experimental design was prepared to cover a wide span of task

loads. To meet this objective it was felt desirable to investigate four levels of track load, two levels of threat complexity, two weapon siting configurations and to a lesser extent, two groups of subjects. The difference in the subjects was that one group had received fewer experimental runs in serving under only one level of weapon-site configuration. Hence, they may be considered less experienced.

The design presented below was intended to permit both the subjects and the referees to function in a reasonable manner and to permit completion of the data collection trials in minimal time. Time was a concern due to the difficulties of scheduling and retaining military subjects who had other duties to perform, because of cost factors and other problems associated with the real-time simulation of complex problems. This design called for each subject to progress through various combinations of conditions under investigation in a stepwise fashion; as his experience increased in the experiment, he faced heavier task loads.

This plan was not a treatment sequence in terms of classical statistical design (22). To investigate fully all combinations of experimental variables in random order would have been prohibitive, both in terms of time and cost. The interest of this investigation was in the practical or indicative types of results, rather than the inferential, statistical type. To a classicist who would ask when is one justified to do studies that are less than complete experiments, the reply might be in order -- "Quantification and methodological sophistication are late products of any science and as such they should be long range goals: mistaking them for proximal goals can render a science impotent". (23)

APPENDIX II
TABLE 2

Weapon Distribution at the Onset of Each Mission

Problem Load Level

Tape Site*		60 Tracks 1-5	60 Tracks 1-8	60 Tracks 2-5	60 Tracks 2-8	72 Tracks 1-5	72 Tracks 1-8	72 Tracks 2-5	72 Tracks 2-8	84 Tracks 1-5	84 Tracks 1-8	84 Tracks 2-5	84 Tracks 2-8	96 Tracks 1-5	96 Tracks 1-8	96 Tracks 2-5	96 Tracks 2-8
Weapon Locations																	
AF$_1$ Red	G	10	5	15	5	20	5	15	5	20	10	20	10	20	5	15	5
	IR	20	10	15	10	20	15	25	15	20	10	20	10	25	15	30	15
AF$_2$	G		5		5		10		10		10		10		10		10
Red	IR		10		10		10		10		10		10		15		15
AF$_3$	G	5	5	3	5	5	5	5	5	5	5	6	3	10	5	5	3
Blue	IR	15	5	10	5	10	5	5	5	15	10	15	10	15	15	16	10
	AW	5	5	2	0	5	5	3	3	5	5	2	2	5	3	4	2
AF$_4$	G	1	3	2	2	5	3	2	1	5	5	2	2	5	7	3	3
	IR	4	4	3	3	5	4	8	4	5	5	5	5	5	0	7	7
	AW	0	0	0	0	0	0	2	2	5	0	0	0	10	5	0	0
	G	5	5	10	5	10	5	7	5	10	3	10	5	20	10	10	5
Green	IR	10	5	20	10	10	5	15	5	15	7	22	10	0	3	25	10
	AW	5	0	5	5	0	0	8	5	0	5	8	5		2	10	2
AF$_5$	G	4			1		4		1		2		3		8		6
Blue	IR	4			4		4		4		8		5		0		2
	AW	0			0		0		0		0		0		3		5
	G	5			5		5		2		2		5		7		15
Green	IR	5			10		5		10		8		12		2		5
	AW	0			0		0		3		0		3				
A			15	25	15		15	25	15		20		20		20	35	20
B		25	15	20	15	25	15	20	15	35	20	35	20	35	20	25	20
C		20	15		15	20	15		15	25	20	25	20	25	20		20

*First digit is the tape number, the second digit indicates number of sites.

APPENDIX II
TABLE 3

Experimental Design

	Sites	Problem Track Loads			
		Tracks			
		60	72	84	96
Group I					
N=6 Mission	5	3*	4	1	2
Threat Level I	8	1	2	3	4
Threat Level II	5 8	2 4	1 3	4 2	3 1
Group II					
N=3					
Threat Level I	8	1	2	1	2
Threat Level II	8	2	1	2	1

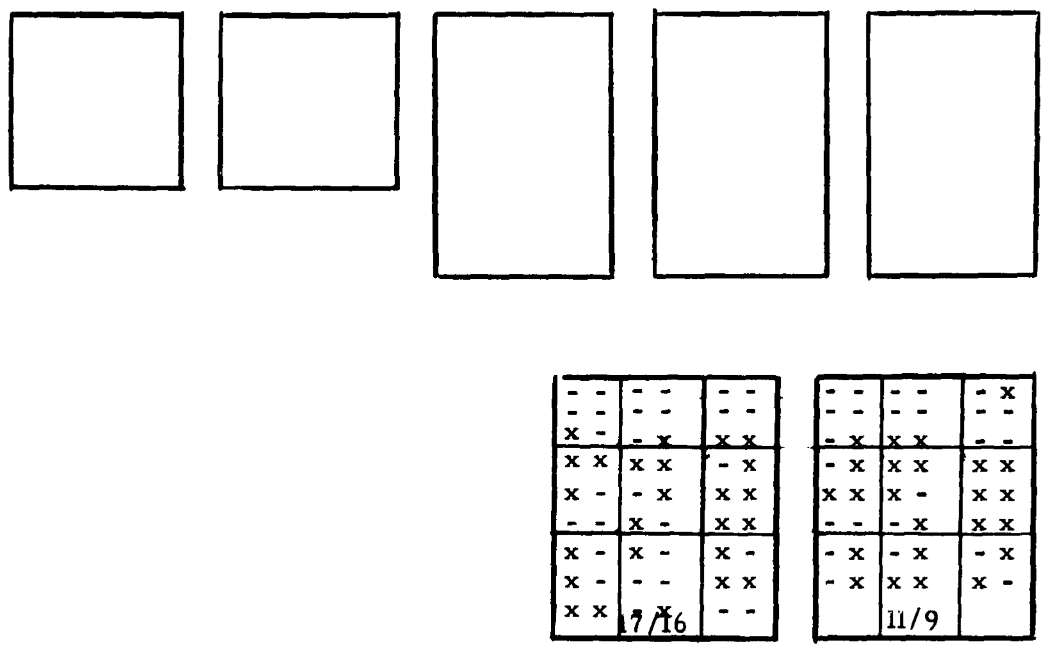
*The run sequence is to read vertically within each subject group.

APPENDIX II

SAMPLE REFEREE SHEETS

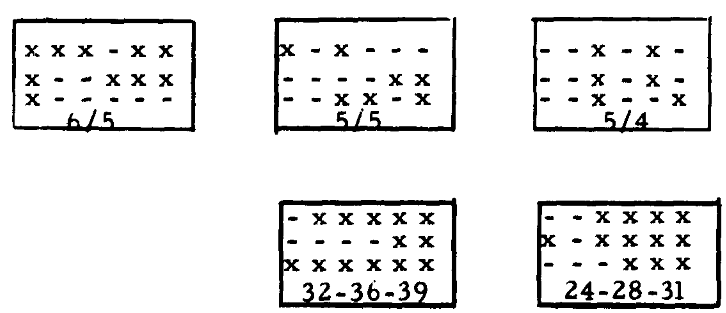
AIRCRAFT

73 -B60 (01-05-43) PMC 24, PMB 32 Damage: 1/2C t34, 1/2B t42 73



MISSILE

73 -B60 (01-05-43) PMC 24, PMB 32 Damage: 1/2C t34, 1/2B t42 73



Electronic Systems Division
L. G. Hanscom Field, Bedford, Mass.
Rpt No. ESD-TDR-61-42. TACTICAL DECISION MAING: I. ACTION SELECTION AS A FUNCTIONOF TRACK LOAD, THREAT COMPLEXITY and WEAPON UNCERTAINTY.
November 1961, 148 p. incl. tables & figures.
Unclassified Report

Performance figures from the first experiment in a series on tactical decision-making in aerospace surveillance are described. Two groups of commanders served under several target load and complexity conditions. Their prime tasks were to evaluate threat and select counter actions to minimize damage and maximize necessary kills at minimum weapon cost. Related tasks were also explored.

(over)

1. Human Engineering
2. Simulation
I. AFSC Proj 4690, Task 46902
II. Fox, W. R.
Vance, W. H., Jr.
III. In ASTIA Collection

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